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ASME RC Baja Challenge: Suspension and Steering

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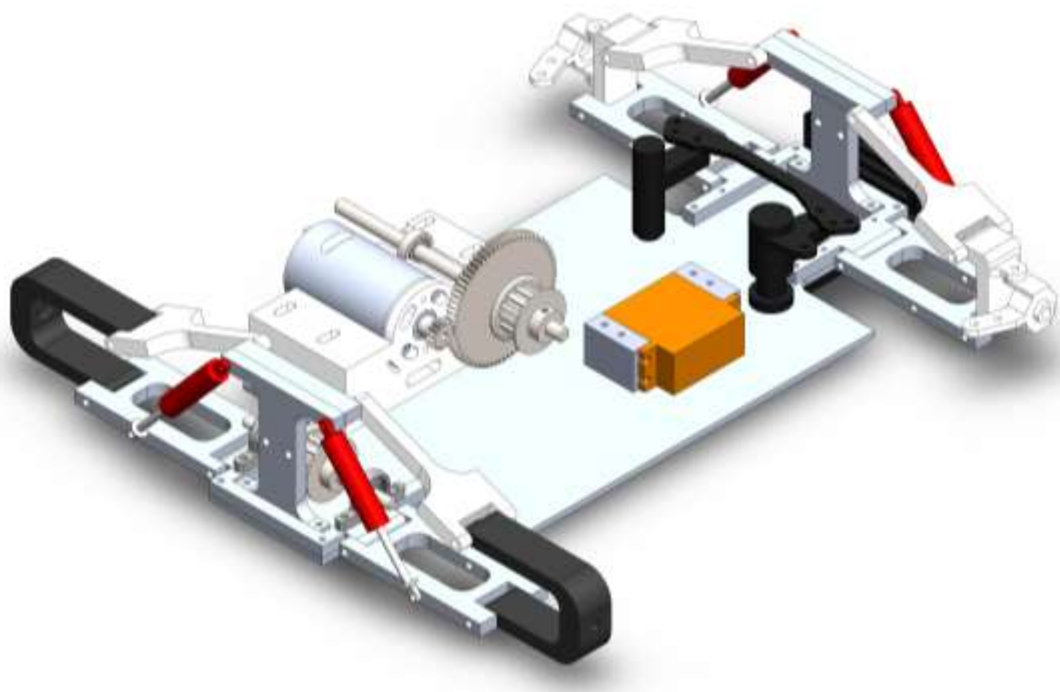

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Abstract

The American Society of Mechanical Engineers (ASME) usually hosts an RC Baja challenge each year, testing a RC car in three events: slalom, acceleration and Baja. Although ASME will not be holding an event this year, CWU will be holding a similar event with three RC Baja car teams from CWU. The RC car that is tested in these events is designed and manufactured typically in teams of two. The RC car that each team submits must be able to complete these events while also remaining competitive. One part of great importance for the RC car is the suspension and steering. This portion of the project focuses on the design, manufacturing, and assembly of the steering and suspension of the RC Baja car, while the other portion of the project focuses on the drivetrain. The RC car for this year features internal-spring shocks that reduce the overall size and profile of the suspension while keeping the performance that is expected of a RC car. The steering system for this year's RC car is a standard bell-crank design that was salvaged from an older RC car. The design of the RC car, which was modeled in SolidWorks and verified with finite element analysis (FEA), shows that the suspension will be able to withstand a drop from 2 feet onto one wheel, a front-end impact when the RC car is traveling at 25 miles per hour, and be able turn with a turning radius of 45 inches.

Introduction

Description

The ASME Baja Challenge features a competition held each year where teams from various colleges and universities design and build an RC car capable of running three events: slalom, Baja, and acceleration. For the 2017 – 2018 academic year, there will not be an official event held for the ASME RC Baja challenge, rather the CWU Engineering Department will hold an unofficial event for the RC Baja cars that will feature three teams total.

Motivation

The motivation of this projects comes from an interest of designing and building an RC car from the ground up rather than purchasing a pre-built RC car. An RC car project would be a comprehensive project that would capsulate the requirements for a capstone project without the risk of having a project that would be too large to manage for an academic year.

Function Statement

A remote-controlled car that can compete in three events as defined by the ASME RC Baja challenge: slalom, acceleration, and Baja. The remote-controlled car will need to be able to propel, steer, and be mechanically sound throughout the events so that the function of the remote-controlled car is not hindered.

Requirements

- The remote-controlled car must be propelled by one 7.2V battery that is intended for remote-controlled cars as defined by the ASME RC Baja challenge.
- The remote-controlled car must be propelled by a "brushed" Mabuchi Motor with a nominal operating voltage of 7.2V
- Assuming a 400-foot Baja course, the remote-controlled car must be able to complete the course in under 272 seconds, equal to moving at an average of 1mph throughout the course.
- The weight of the RC car must be less than or equal to 5 pounds.
- The velocity of the remote-controlled car must be sustained at least 11mph over a length of 20 feet.
- The suspension of the car must be able to support a drop of 2 feet onto one (1) wheel.
- The steering of the car must be able to have at least 170° turn angle.
- The suspension of the car will include a "spring over shock" system.

Success Criteria

The success criteria of the ASME RC Baja car will that it will be able to compete in the ASME RC Baja challenge. The ASME RC Baja challenge will be defined by the CWU Engineering Department as there will be no ASME-sponsored event this academic year. The RC Baja car will need to be able to compete in all of these events without breaking, falling apart, failing, or otherwise unable to complete any of the events completely.

Scope

The scope of this project will be to design and build the suspension and steering of the RC Baja car. The suspension and steering of the RC Baja car will need to conform to the guideline set forth by the ASME RC Baja Challenge. Some part of the suspension (such as the nuts, bolts, etc.) and the steering (such as the servo) will be store bought while much of the rest will be designed, manufactured, and constructed. The remainder of the car, which includes the drivetrain and the chassis, will be designed, manufactured, and constructed by Nick Paulay, who will have his own requirements for his scope of the project that the RC car will need to conform too.

Benchmarks

Benchmarks for our RC Baja car includes past RC Baja cars that were built at CWU by teams as part of the capstone project class. During the 2016 – 2017 academic year, the ASME RC Baja challenge was completed by Michael Cox and Jason Moore. During the 2015 – 2016 academic year, the ASME RC Baja challenge was completed by Chelsea Dowdell and Nathaniel Wilhelm. Along with the CWU RC Baja teams, teams from other universities from around the United States will serve as a benchmark for our RC Baja car.

Success Criteria

The project will be deemed successful if the RC Baja car is able to compete and finish in all events. Finishing all events will rely on the RC Baja car to move about the courses without falling apart or otherwise being prevented from completing any other the courses.

Design and Analysis

Approach: Proposed Solution

The proposed solution will be designing and constructing a suspension and steering system that will be able to compete in the three ASME RC Baja Challenge events: acceleration, slalom, and Baja. The design will feature parts and features that have worked in the past but will feature a spring-over-strut suspension rather than a leaf spring style suspension that has been used in past events. The budget will be limited to $500 as to not allow the project cost to become excessive.

Design Description

The first component of the suspension is the A-arm, which connects the chassis to the wheel hub. The A-arm will be the same design on both the front and rear axle to allow easy replacement of the A-arm if they fail. The A-arm is connected to the chassis via a pin which allowed rotational travel in the X-Y plane but does not allow travel in the Z-plane. The A-Arm will also connect the wheel-hub to the chassis via a pin. The wheel hub consists of the caster block, hub carrier, and the steering knuckle, depending on which axle the A-arm is located. The caster block defined both the caster and camber of the wheels. The caster, or caster angle, is defined “forward or backward slope of a line drawn through the upper and lower steering pivot points when viewed directly from the side of the vehicle."[1] The camber is defined by "how far the tire slants away from vertical when viewed directly from the front or back of the vehicle."[2] For the design of the RC Baja car, the caster and camber angle will be set to 0°.

The RC Baja car will feature a steering system that is driven by a servo and will be mounted to the front axle of the RC Baja car. The servo will include linkages that will connect the servo to the steering knuckles on the front axle. The servo will rotate which will affect the angle at which the tires are rotating, which will turn the RC car. The RC car will be driven by a driveshaft that will be located to the rear axle of the RC car, making the car rear-wheel drive. The rear axle will differ from the front axle as there will be no steering knuckles, but rather a hub carrier, which will hold the driveshaft from the motor to the tires.

The suspension of the RC Baja car will feature a spring-over-shock design. The shocks will connect the A-arm to the chassis via a shock tower. This will allow the RC car to absorb any forces that it may encounter during competition and will provide a smooth ride for the RC Baja car. The shock will be the same on both the front axle and rear axle to ensure easy replacement of parts if they fail.

Benchmark

This project will be benchmarked against previous ASME RC Baja car from teams that have competed by Central Washington University. The benchmark will primarily be conducted by the proposals and reports of the previous teams.

Performance Predictions

The suspension will be able to move over a height differential of 1.5" and will survive a 24" drop onto one wheel. The suspension will be able to support a weight of 5lbs when the vehicle is at rest and during normal operation. The steering system must be able to turn within a 45" turning radius without having any interference with any other features on the RC Car.

Description of Analysis

Approach Sequence

- Use equations of energy to determine the energy needed to be absorbed by the suspension
- Determine the forces that will be applied to the suspension.
- The model suspension system in SolidWorks based on analysis, and determine if fits and mates are correct.
- For impacts to the a-arms of the RC car, use SolidWorks simulations to verify the analysis.
- Determine the angles required to complete a 45" turning radius.

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[1] TireRack.com
[2] Ibid.

- Determine Ackermann Steering Geometry using the geometry of the RC car.

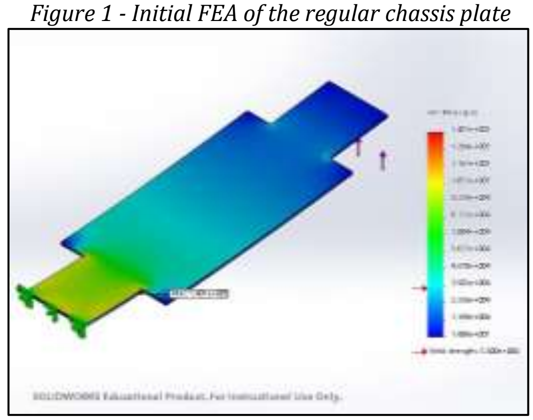
Analysis of Suspension

To begin the analysis of the suspension, the team needed to determine the amount of force and the amount of energy that would be absorbed by the RC car if it were to be dropped from a height of 24” onto one wheel and the force if the RC car were to be 5 pounds. From the analysis, it was determined that if the RC car was to fall from 24” onto one wheel, the car would need to absorb 10ft-lb_f of energy and survive a 160lb_f placed onto the spring, which assumes the spring travels 1.50 inches, which would be the maximum travel distance that the spring would travel (Appendix A, page iii, Figure 7). The energy analysis can be seen in Figure 5, Figure 6, and Figure 8 in Appendix A pages i - iv.

Another force that the RC car could experience would be if the chassis plate were to contact an object while moving at full speed. While a sufficient clearance would allow the RC car to move over the object without contact, in a scenario where the RC car would contact an object with sufficient size. The chassis plate would need to be able to survive the force of striking an object. If the RC car were moving at 20 miles per hours, the force that RC car would experience would be about 50 pounds.

The chassis plate was to be made from 6061-T6 aluminum as this material was easily sourced and provided an adequate amount of yield strength at 30000psi and while remaining light in weight with a density of 2.16 g/cm^3.

Figure 1 - Initial FEA of the regular chassis plate



The chassis plate would need to survive a force of 50lbs at the end of the plate. Figure 1 shows FEA of the chassis plate if the plate were contacted by an object at the front. This plate would ultimately yield at the stress concentrations in the rear. This chassis plate would not be suitable as if the plate were to be contacted and the plate was to yield, vital components to the RC car would be exposed to failure.

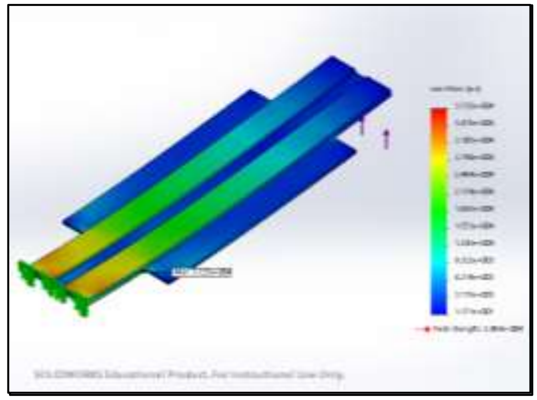


Figure 3 - FEA of the 3rd plate revision

There were a few options moving forward to ensure that the chassis plate would survive an impact to the front, such as a material change, or a redesign of the chassis plate. Since the weight of the RC car is a substantial requirement to the success of this project, it was determined that the chassis plate would need to be redesigned. The second revision to the chassis plate included ribs to increase the resistance to the bending of the chassis plate. Figure 2 shows the revised chassis plate with the added ribs and the FEA of the part if it were to be contacted by an object. Although the ribs help the chassis plate from not failing at the stress concentrations in Figure 1, the plate will still yield if it were to contact an object.

The final revision of the chassis plate would still include ribs but would increase the width of the ribs. Figure 3 shows the final plate revision with the winder ribs. This revision does not yield when placed under a load of 50lbs and has a safety factor of 1.07. Analysis of the chassis plate can be seen in Figure 14, Figure 15, and Figure 17 in Appendix A pages x, xii, and xiii.

Through the resign of the RC car, which included changes to the caster block mount, rear hub carriers, control arms, and steering knuckles, the rear hub carriers had a major change in design, which was needed to incorporate the rear drive shafts. Originally the rear hub carriers needed to just hold the rear drive shafts and bearing, but with the measurement of the rear driveshafts being incorrect, the rear hub carriers needed to be redesigned to allow the rear driveshafts to fit within the space of the rear suspension. Figure 29 shows the current design of the rear hub carriers, which features a lengthier design that will be able to hold the rear driveshafts. Given the new design, it was necessary to determine the bending stresses if the rear hub carriers held a 10-pound force on the top of the hub carriers, which was a liberal estimate if the RC car was to be inverted and lay topside on the ground. Figure 17 shows the analysis of the rear hub carriers, and when they sustain a 10-pound force on the top, the maximum bending force that should be expected was 2162 psi. It should also be noted that given the area that the failure may likely occur, there are multiple sized holes, which would produce a stress concentration. The bearing that would fit into this area may allow some support in the instance of a bending moment and may be useful in the design of the RC car.

Analysis of Steering

The primary method of analyzing the steering of the RC Baja Car is using the Ackermann Steering Geometry. The analysis of the Ackermann Steering Geometry can be found in Appendix A page xi. Based on the size of the wheelbase and the distance between the axis, the Ackermann angle was found to be 69.4° and was incorporated into the design of the steering knuckles.

Device Assembly

Attachments

Some parts that will be included in the final assembly that will serve to attach and fasten the RC car together will include:

- Linkages
- Fasteners
- Pins
- Tires
- Servo
- Nuts

Methods and Construction

There will be two types of manufacturing process that will be applied to the suspension and steering components: machining and 3D printing.

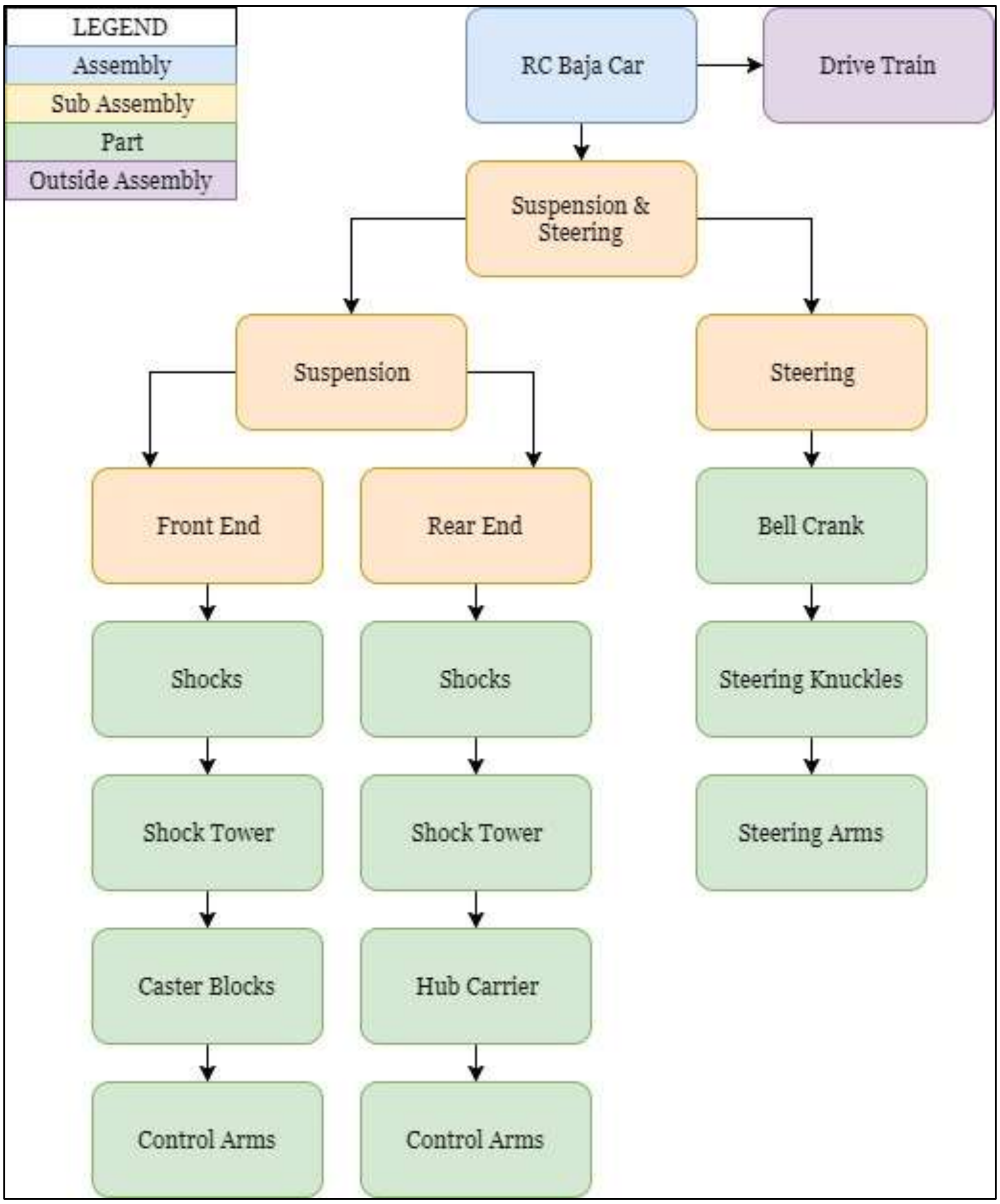
For the machining of parts, the primary location that this will take place will be in the Central Washington University's Hogue Hall Machine Lab. In the machine lab, the manufacturing of the RC Baja Car will make use of mills, drill presses, lathes, and CNC machines. Many of the parts will also be manufactured by Alcobra Metals, located in Spokane, WA, where they will be waterjet the overall shape of the parts, while the team will be responsible for the remainder secondary processes, such as drilling and tapping.

For the 3D printing of parts, the primary location that this will take place will be in the Central Washington University's Hogue Hall Rapid Prototyping Lab. The primary process that the parts will be designed for the Rapid Prototyping lab will be through the use of SolidWorks, while outside parts and other programs may also be used.

Construction of the RC Car began in the latter half of the winter quarter, where the parts were completed and all necessary auxiliary parts, such as pins, screws, nuts, and axle arrived after being bought. The team quickly realized that there were a few issues with regards to the fitment of some of the parts. Some parts, such as fastening the suspension mount to the chassis, were not designed with a reasonable clearance, which required some screws to be forced into their respective threads. Some of the clearance holes were not within their tolerances and as a result, some screws were not able to be used on the RC car. The rear hub carrier originally did not allow the rear axles to fit with the given space. The issue that caused the problem was the original measurement, where the length of the axle was expected to be from the middle of the chassis, towards the end of the control arms. The measurement should have been taken where the shaft would have started, which would be approximately where the control was connected to the chassis. While this issue arises late into the construction, this was mitigated by redesigning the rear hub to allow the axle to fit into place.

Drawing Tree

Figure 4 - Drawing Tree of the RC Baja Car



Parts List

The most current parts list can be found in Appendix C – Parts List, Costs, and Budget

Testing Method

Introduction

The primary was to test the RC Baja car's steering and suspension will be to use the environment both within Hogue Hall and the outside environment. Inside of Hogue Hall, the environment can be controlled where obstacles and the ASME Baja challenges courses and be built and the RC Baja car can be run through a course that would be similar to what the final ASME Baja challenge courses would be, In the outside environment, there are multiple factors that are uncontrolled and the RC Baja car will be subject to uncertainty. The RC Baja car can be placed on dirt, rocks, or in a wet or dry environment where the RC Baja car can be tested to see if it can operate in different environments that it would not normally operate.

Approach

The tests will primarily take place inside of Hogue Hall where the environment can be created and controlled. This environment is ideal as there are multiple resources available so that many challenges, tests, and courses that can be created in a controlled environment. Some of these resources include boxes, lumber, concrete, and raised platforms can be used to control the height of the RC Baja car if a drop test was performed. If a simulation of the outside environment was to be performed, there are multiple types of surfaces and conditions that can be brought in from the outside and recreated inside of Hogue Hall.

Procedure

When testing the ability of the suspension of the RC Baja car to absorb a 2-foot drop test, the RC Baja car will drive off of a raised, measured surface. For this test to be measurable, the height of the raised surface along with the final mass of the RC Baja car will be needed to calculate the energy the car is expected to absorb. This test will be graded on a pass/fail system. To pass this test, the RC Baja will need to operate as expected after driving and fall off the raised surface.

When testing the ability of the RC Baja car to drive in a straight manner, the RC Baja car will be put through a course where two 30 foot lengths of tape will be placed on the ground parallel to each other at a width of 12 inches. The RC Baja car will be making multiple runs between the two lengths of tape at varying speeds. This test will be graded on a pass/fail system. To pass this test, the RC Baja car must not have one wheel fully outside of either length of tape during the run of the course. This test will be running at 10%, 25%, 50%, and 100% of the maximum speed possible.

When testing the ability of the RC Baja car to climb onto and over obstacles, a system of 2x4 boards will be fastened to the ground. The boards will either increase or decrease in height at an interval of 1.5 inches. The RC Baja car can move through this course at any speed as long as the RC Baja car continues to move forward. To pass this test, the RC Baja car will need to complete the course fully without failing to cross over any of the boards or tipping or falling over.

Budget, Schedule, and Project Management

Proposed Budget and Funding Source

The proposed budget that will be set for this project will be $250. This budget will come directly from the team members own money. The budget for this project is not a strong consideration with regards to design decisions or product sourcing. An estimated cost for the project can be found in Appendix C – Parts List, Costs, and Budget.

The final cost of the device came out to be approximately $513.01. This brought the project well over budget from the original estimate of $250. The reason for the project for going over budget was due to the use of a third-party waterjet cutting many of the parts, parts needing to be re-printed and some auxiliary parts not having correct lengths. The material that was bought, when the original plan for manufacturing was for the team to fabricate all of the parts, was a sunk cost as there was no viable way to retrieve some of the cost to purchase the material. The RC car went through a few small redesign phases during manufacturing and as a result, some parts needed to be changed and required some parts to be 3D printed multiple times.

Suppliers and Material Acquisition

Due to no parts from the previous years' RC cars are available, this project will be purchasing all materials and parts from various sources, which will inevitably increase our costs over other RC car projects. The raw materials, such as aluminum bars and rods, will be sourced through Metals Depot. Metals Depot provides custom sizes with regards to cut length for a reasonable price and sources the correct aluminum alloy needed for this project. Other suppliers that will be considered for this project will be Amazon and RC Planet. Amazon has great selection variety and great return policies if parts are not fitting correctly or arrive broken. RC Planet is an RC-focused online store that sells a variety of parts for RC cars and provides clear specifications for the parts that they sell. The team will be using Alcobra Metals, located in Spokane, WA to have many of the parts waterjet cut. This will allow the parts to meet small tolerances while accelerating the manufacturing of the project.

Proposed Schedule

Gantt Charts

Gantt charts are useful graphical representations of estimating timelines for completion. They provide a description of the task, the timeframe, whether it may be days, weeks, or months, and the amount of time the task may take. As this project will take approximately 9 months to complete, the Gantt charts used in this project will use weeks as the time frame resolution. The Gantt charts will be split up into each quarter so that the charts may be viewed accurately and may be adjusted as the project progresses. Figure 37, Figure 38, Figure 39, and Figure 40 shows the Gantt Charts for each phase of the project. Given the progress of the manufacturing and the assembly of the project, which is what Figure 39 is based on, currently, the project is coming in ahead of schedule. The factors behind the project being ahead of schedule have to do with the manufacturing changes made during the project, the ease of the manufacturing of parts that needed to be redesigned and the extra time that the team estimated for the manufacturing process. Many of the aluminum parts of the project were sent to Alcobra Metals in Spokane, WA to be waterjet cut which reduced the manufacturing time considerably, which was seen in previous estimates where the total manufacturing and assembly time was estimated to be approximately 240 hours and was brought down to the current estimated time of 148.8 hours, saving nearly 100 hours in project time. The parts that were re-designed during the manufacturing process were all 3D printed parts. While some considerations were made to have the parts that were waterjet cut redesigned, the costs associated with having those parts waterjet cut again did not make that feasible. Instead, the team focused on re-designing parts that were 3D printed so that the assembly of the RC car could take place more easily and allowed the project to function correctly.

Milestones

The use of milestones is a visual way of determining how the project is progressing. Milestones such as completing the website, making the first part, or completing testing provide an excellent way to determine if the project is progressing as expected or if the project is moving fast or slow.

Total Project Time

Based on the estimated time in the Gantt charts for each quarter, which can be found in Appendix D, Figure 29, Figure 30, and Figure 31, this project will take 248.8 hours to complete. Due to the high project time duration, it is essential to remain on time and not get behind on the project. Going forward into the winter quarter, this approximation may change due to the timeframe of making parts and assembling the RC car takes place and a more accurate estimate can be completed. After extensive revisions to the project, the total manufacturing and assembly time was reduced to an estimated 137.3 hours based on the time saved by having Alcobra Metals waterjet cutting many of the parts.

Project Management

Human Resources

The primary human resources will be the project owner, the project partner, Dr. Johnson, Prof. Pringle, Prof. Beardsley, Ted Bramble, and Matt Burvee. These individuals may provide guidance on how to approach the project, design elements of the RC car, and how to create, machine or otherwise make the parts.

Physical Resources

There are multiple physical resources that will be available to complete the project such as the machine shop, the SolidWorks lab, and the rapid prototyping lab. The rapid prototyping lab consists of two 3D printers that will prove useful in having parts 3D printed quickly while the machine shop is stocked with multiple lathes, mills, drill presses, and CNC machines. For many of the parts, the team will make use of a waterjet to cut the simple 2D parts. The waterjet is owned by Alcobra Metals in Spokane, WA and the team will contract them to make use of the waterjet.

Discussion and Conclusion

Design Evolution

The major design change for this project focused on the material used throughout the project. Originally, the suspension supports, a-arm, and steering system were going to be comprised of printed ABS for the manufacturing of the parts. While the benefits of having each part 3D printed included a lighter weight, cheaper material, and easy to source, the printed ABS has a lower strength than aluminum, and through suggestions made to the team from the advisors, and based on the experiences from teams in the past, it was determined that the printed ABS could not and shouldn't be expected to hold up against the started operation of the RC car.

Moving forward from the printed ABS was to determine if aluminum could be a suitable replacement for the Printed ABS. While aluminum is about 2.5 times as dense as the printed ABS, which would make the RC car heavier, aluminum is about 14 times stronger than printed ABS, which after consulting with the advisors and looking at past experiences with other projects, aluminum was chosen as the primary material to be used throughout the project.

Some smaller parts, such as the steering knuckles and caster blocks, will continue to be 3D printed as some of their design are more complex and would require extensive machining to create the part, which would pose an issue if the part would need to be machined if the part failed.

Many of the parts that were expected to be manufactured by the team were instead waterjet cut by Alcobra Metals. This allowed the team to move away from fabricating small, complex parts and instead focus on the fitment and eventual construction of the RC car. During the manufacturing, the team realized that some of the parts, such as the caster block mount, could instead be 3D printed which proved useful as this part would have been difficult to manufacture given is small size, complex shape, and difficult secondary manufacturing processes.

Project Risk Analysis

When analyzing the risk of the project, there are three things to consider in the scope of the entire project: cost, schedule, and project management.

When considering the cost of the project, the proposed budget for the suspension and chassis is going to be $250. The primary problem, when associated with the cost, would be material costs. Aluminum sheets, bars, and flats can upwards of $50, so by optimizing the design with standard shapes and sizes of aluminum stock, the costs may be reduced significantly.

When considering the schedule of the project, the ASME RC Baja challenge has been completed before and should be feasible for any team to complete. The main issues arising with the schedule of the project would rest on the complexity of the parts of the RC Baja car, the shipping of RC Baja car parts, and the installation and construction of the RC Baja car. More complex parts will require extensive machining if the parts are not 3D printed. The shipping of certain parts of the RC Baja car rests on the companies that ship those parts, so sourcing the parts only from the United States will reduce wait times. Installation and construction time may be hampered if unforeseen parts do not want to mate or connect properly, which will require a re-design of the part.

When considering the management of the project, the primary issue that will be apparent will be the collaboration between partners and the time frame that can be spent working on the project. The partners are not always available to be working together on the parts and the partners are not always available to continuously work on the RC Baja car. Efficient time management and set milestones and goals will be crucial to finishing the RC Baja car in time.

Phase Success and Looking Forward

The team moved well ahead of schedule by allowing many of the parts to be waterjet cut rather than manufactured by the team. The quick turnaround time of one week for the waterjet cut parts and moving some parts away from aluminum and into a 3D printing process allowed for more time to be spent constructing the car and altering any parts when construction issues became a problem. Some of the issues with fitment of screws and parts mating did not pose any large issues that could be mitigated easily and no major rework of critical parts did not need to occur due to careful manufacturing by the team, ensuring that the parts would fit and would be within expected tolerances. This phase will be considered successful if all parts can come together and the RC car will function as expected. The final successes criteria for this phase will be a working RC car, where it will be moving, turning, and climbing over obstacles. Looking forward to the next phase, testing will mean putting the RC car through rigorous tests that will push some of the limits of the RC car. Some of these tests, such as the drop test, turning test, and acceleration test, will showcase what the RC car is capable of and if the design of the RC car will match with the original success criteria.

From the experience of designing, manufacturing, and assembling the RC Baja car, there have been a few major points that have stood out to the team. The first point that was made to the team was that designing the parts of the RC Baja to some of the bought parts is difficult if the parts are not already available. Once the front end was assembled, it was noticed by the team that the steering was obstructed as the tire was obstructed by the control arm when the steering angle was nearly at its maximum. Going forward, it may be necessary to remove some of the material from the control arm with the goal of not hampering the performance of the control arms or the steering. Another major point from this experience has been the fitment of some of the parts. While designing the parts in SolidWorks and Onshape, some of the mating features did not have any type of the clearance between parts, which was an oversight of the team. When assembling the RC Baja car, the lack of clearance was readily apparent as fitting some of the parts required filing, grinding, and cutting so that there was a clear fit for the parts. While the team has to adjust on the go to make some of the parts mate correctly with each other, the only issue this posed to the team was increasing the time required to assemble the RC car. The third major takeaway from this project was an issue of the front wheels being loose and not having great rigidity. This issue stemmed from not having an equal length upper control arm and a lower control arm. When the wheel rotates inwards or outwards, the camber of the wheels does not follow a perpendicular path to the ground, causing the wheels to have a negative camber when on the ground. This issue may be fixed by adjusting the upper control arms to match the length of the lower control arms, having the main axis of rotation be collinear with each other, and having both control arms be parallel to each other. Another major takeaway from this project was the lack of collaboration during the design phase of this project. While both team members worked on their side of the project, when it came time to manufacture and assemble the RC car, it was clear that the team members have two different ideas for the size requirements of the car. This difference caused the removal of the second gear reduction of the RC car due to the size constraints. Going forward, if the RC car does not have sufficient torque to be competitive, it may be necessary to redesign the rear pulley area to accommodate as large of a reduction as possible.

Acknowledgments

The team would like to thank Central Washington University for allowing this project to move forward and to be a source of inspiration and help during this project. Thank you to Dr. Craig Johnson, Mr. Roger Beardsley, Mr. Charles Pringle, Mr. Ted Bramble, Mr. Matt Burvee, Mr. Nolan Stockman, and Mr. Jeff Wilcox for the guidance during this project that allowed the team to come to a solution for this competition that will make us competitive during competition. An extended thank you to Lucas Beechinor and Alcobra Metals, Inc. in Spokane, WA for allowing the team to have parts waterjet cut at an amazing price and timeline, allowing the project to move well ahead of schedule.

References

[1] Project Management Institute, *A Guide to the Project Management Body of Knowledge*, Project Management Institute, Inc., Newtown Square, PA.

[2] Lackey, W., 2017, *ASME Baja RC Car Drivetrain*, Central Washington University.

[3] Moore, J., 2016, *ASME Mini RC BAJA: Drivetrain*, Central Washington University.

[4] Cox, M., 2016, *ASME Mini-Baja RC CAR (Steering and Suspension Systems)*, Central Washington University.

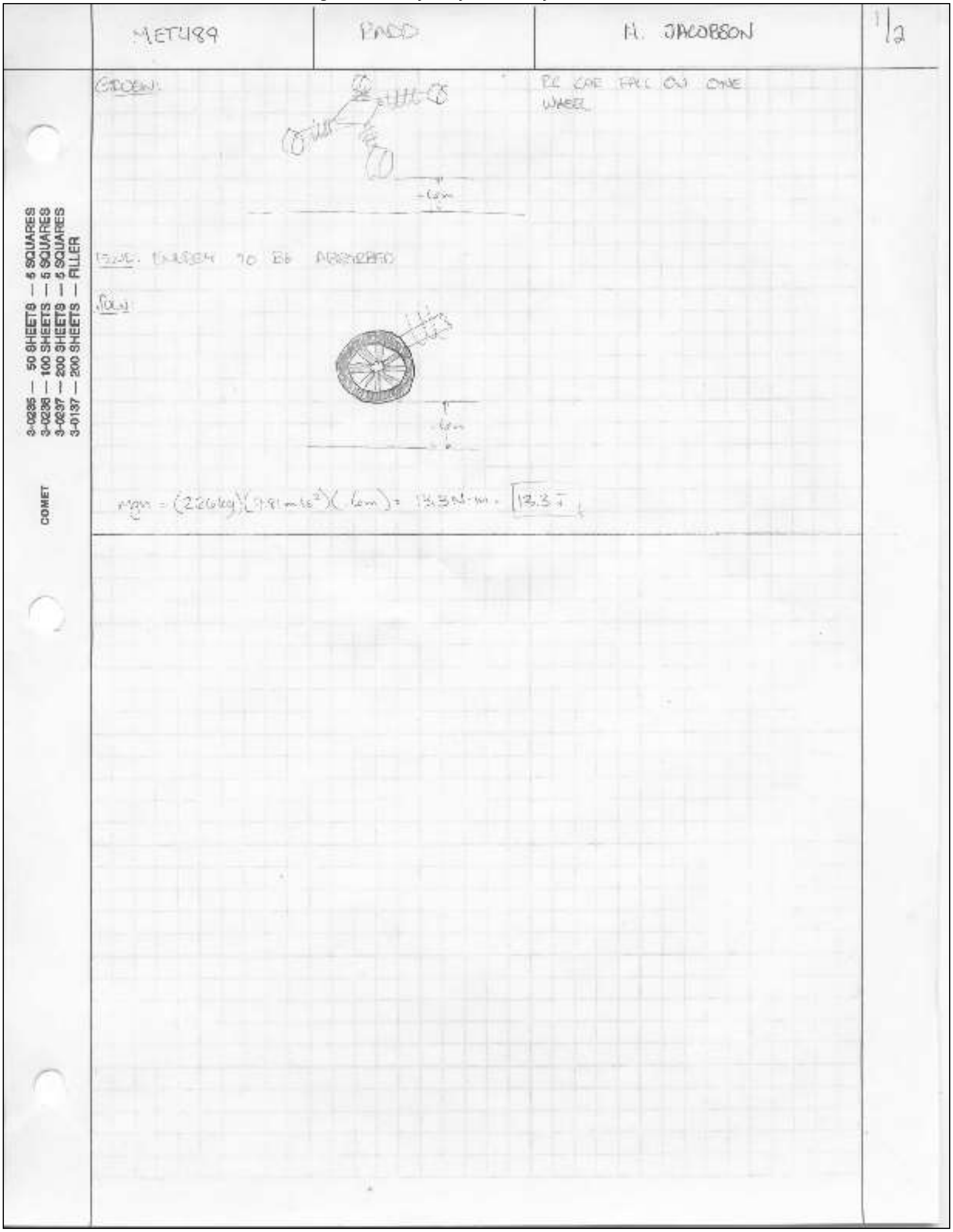
[5] Wilhelm, N., 2015, *ASME R/C BAJA CAR Suspension and Steering*, Central Washington University.

[6] Mott, R., 2014, *Machine Elements in Mechanical Design*, Pearson, Boston.

[7] Dowdell, C., 2016, *RC Baja Competition Drive Train and Differential*, Central Washington University.

Appendix A - Analysis

Figure 5 - Analysis of the RC Baja Car shocks



MET489 | BADD | H. JACOBSON | 1/2

GIVEN: RC CAR FALL ON ONE WHEEL

6cm

FIND: ENERGY TO BE ABSORBED

SOLN:

6cm

$mgh = (226kg)(9.81\,m/s^2)(6cm) = 13.3\,N\text{-}m = \boxed{13.3\,J}$

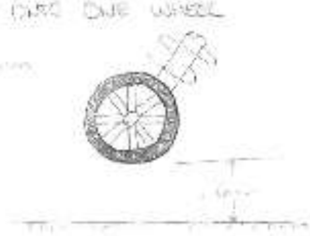
Figure 6 - Analysis of the RC Baja Car shock falling onto one wheel

MET489	[illegible]	N. JACOBSON	2/2

GIVEN: RC CAR FALLING ONE WHEEL

SPRING LENGTH = 25.4 mm

$E_{absorbed} = 13.3\,J$



FIND: REQUIRED SPRING CONSTANT

SOLN

$\frac{1}{2}kx^2 = 13.3\,J$

$k = \frac{26.6\,J}{x^2} = \frac{26.6\,N\cdot m}{(.0254\,m)^2} = 41230\,N/m$

$41230\,N/m\left(\frac{.2248\,lb}{1N}\right)\left(\frac{1m}{39.4\,in}\right) = 235\,lb/in$

DETERMINING SPRING TO PURCHASE

SUPPLIER	OUT. LEN.	RATE	PT. NUMBER
SPRINGFAST	1"	360 lb/in	C16-045-072
SPRINGFAST	1"	366 lb/in	C[illegible]
[illegible]	1"	356 lb/in	C[illegible]
[illegible]	1"	231 lb/in	[illegible]

IF SPRING CONSTANT OF 360 lb/in, S.F. OF APPROX. 1.34, FIND SPRING TRAVEL DISTANCE UNDER SAME PARAMETERS

$360\,lb/in\left(\frac{1N}{.2248\,lb}\right)\left(\frac{39.4\,in}{1m}\right) = 63100\,N/m$

$\frac{1}{2}kx^2 = 13.3\,J$

$x = \sqrt{\frac{26.6\,J}{k}} = \sqrt{\frac{26.6\,J}{63100\,N/m}} = .0205\,m\left(\frac{39.4\,in}{1m}\right) = \boxed{0.808\,in}$

Figure 7 - Analysis of forces placed onto shocks

METH489	SUSPENSION ANALYSIS	H. JACOBSON

GIVEN:

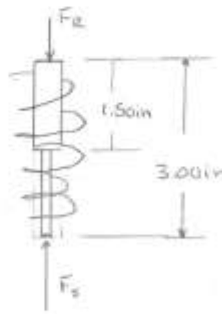
$k = 106.7 \frac{lb_f}{in}$

$x = 1.50in$

ASSUMES SPRING WILL TRAVEL FULL DISTANCE

FIND: SPRING FORCE

SOLN:



$\Sigma F_y = 0$

$0 = F_s - F_R$

$F_s = F_R$

$kx = F_R$

$(106.7 lb_f)(1.50 in) = F_R$

$\boxed{F_R = 160 lb_f}$

$mgh = (5 lb_m)(32.174\ ft/s^2)(2\ ft)$

$= 321.74 \frac{lb_m \cdot ft^2}{s^2} \cdot \frac{1\ lb_f}{32.174 \frac{lb_m \cdot ft}{s^2}} = 10\ ft \cdot lb_f$

$1/2\ kx^2 = mgh$

$1/2\ kx^2 = 10 ft \cdot lb_f$

$k = \frac{2(10\ ft \cdot lb_f)}{(.125\ ft)^2} = \frac{1280\ lb_f}{ft} = \frac{106.7\ lb_f}{in}(1.50 in) = \boxed{160\ lb_f}$

Figure 8 - Analysis of the RC Baja Car chock falling onto all wheels

MET489	ANALYSIS OF SUSPENSION	[illegible] JACOBSON	1/1

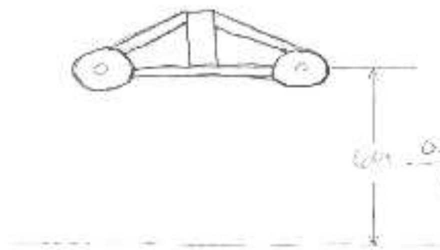
GIVEN:

WEIGHT OF RC CAR = 3lbs
HEIGHT OF RC CAR OFF GROUND = 6ft

FIND:

ENERGY AS RC CAR HITS FLOOR

SOLN:



$6ft \cdot \frac{0.3048\,m}{1ft} = 1.829\,m$

$E_{initial} = PE + KE^{\,0}$
$= mgh + \cancel{\tfrac{1}{2}mv^2}$

$3\,lbs \cdot \frac{4.44822\,N}{1\,lbs} = 13.34\,N$

$\frac{13.34\,N}{9.81\,m/s^2} = 1.360\,kg$

$= (1.360\,kg)(9.81\,m/s^2)(1.829\,m)$
$= 24.40\,\frac{kg\,m^2}{s^2} = 24.40\,N\cdot m$

$\boxed{= 24.4\,J}$

RC CAR NEEDS TO SUPPORT 24.1 J ON DROP OF CAR THROUGH SUSPENSION AND FRAME

Figure 9 - Analysis of the lower control arm

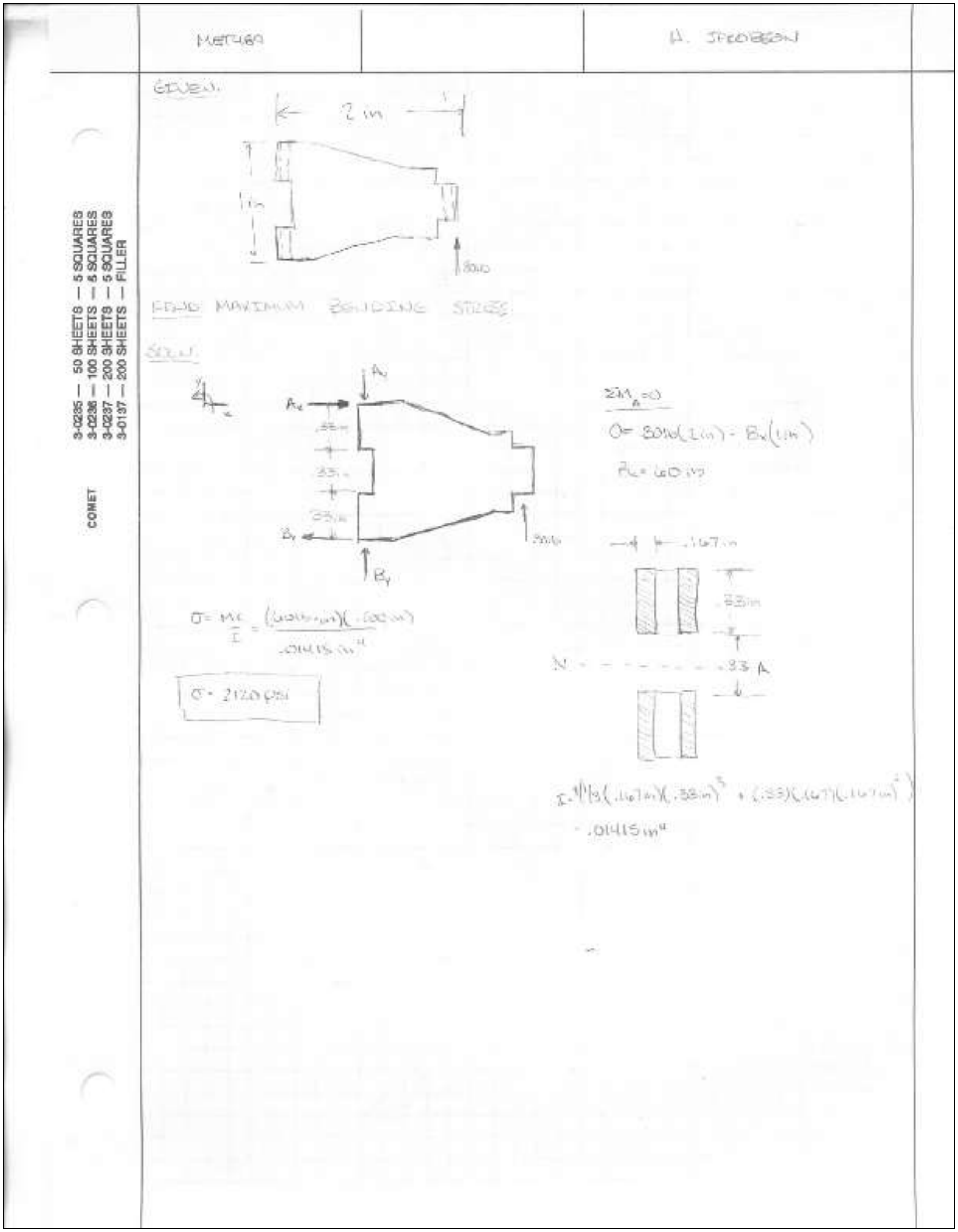


Figure 10 - Analysis of the clearance

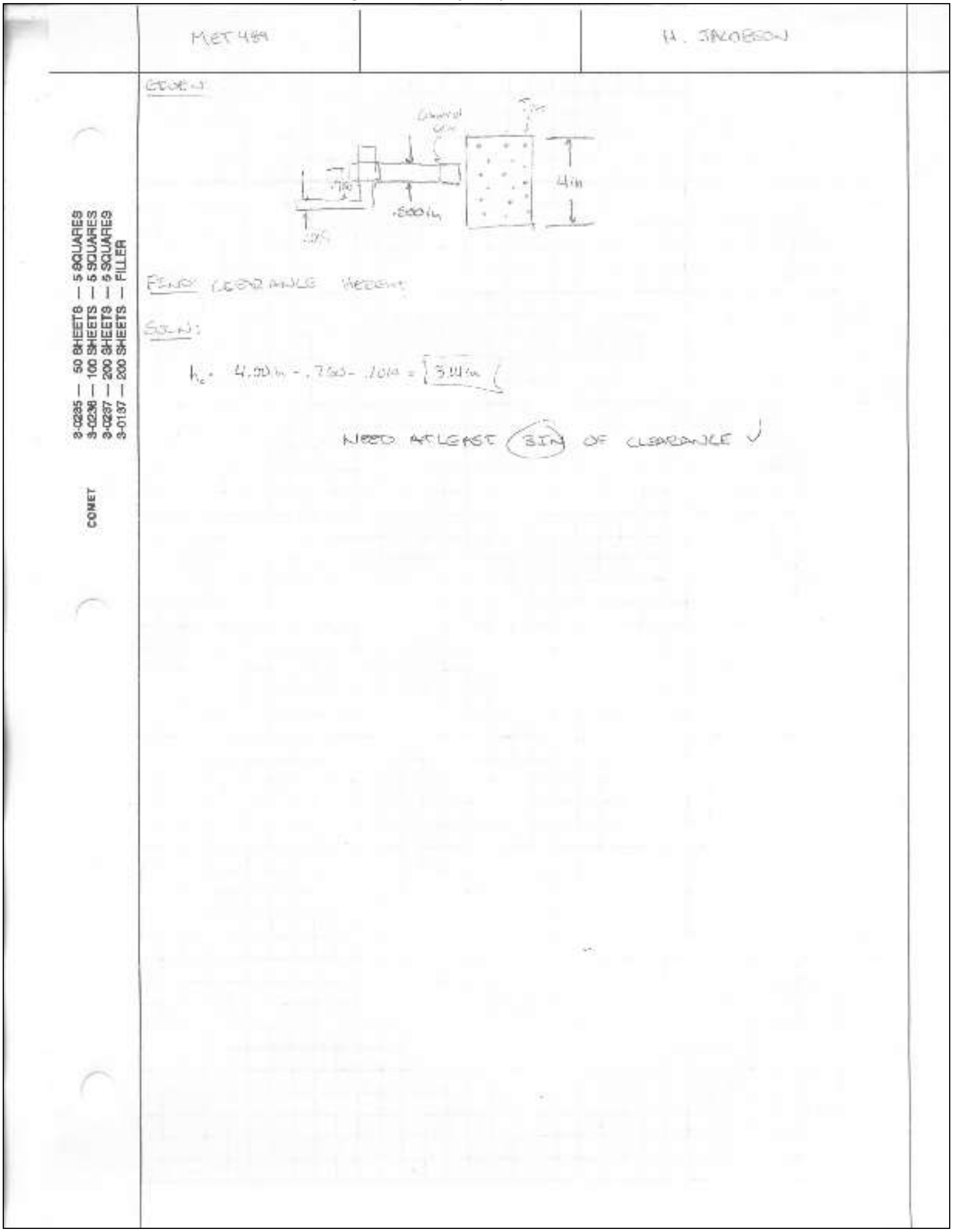
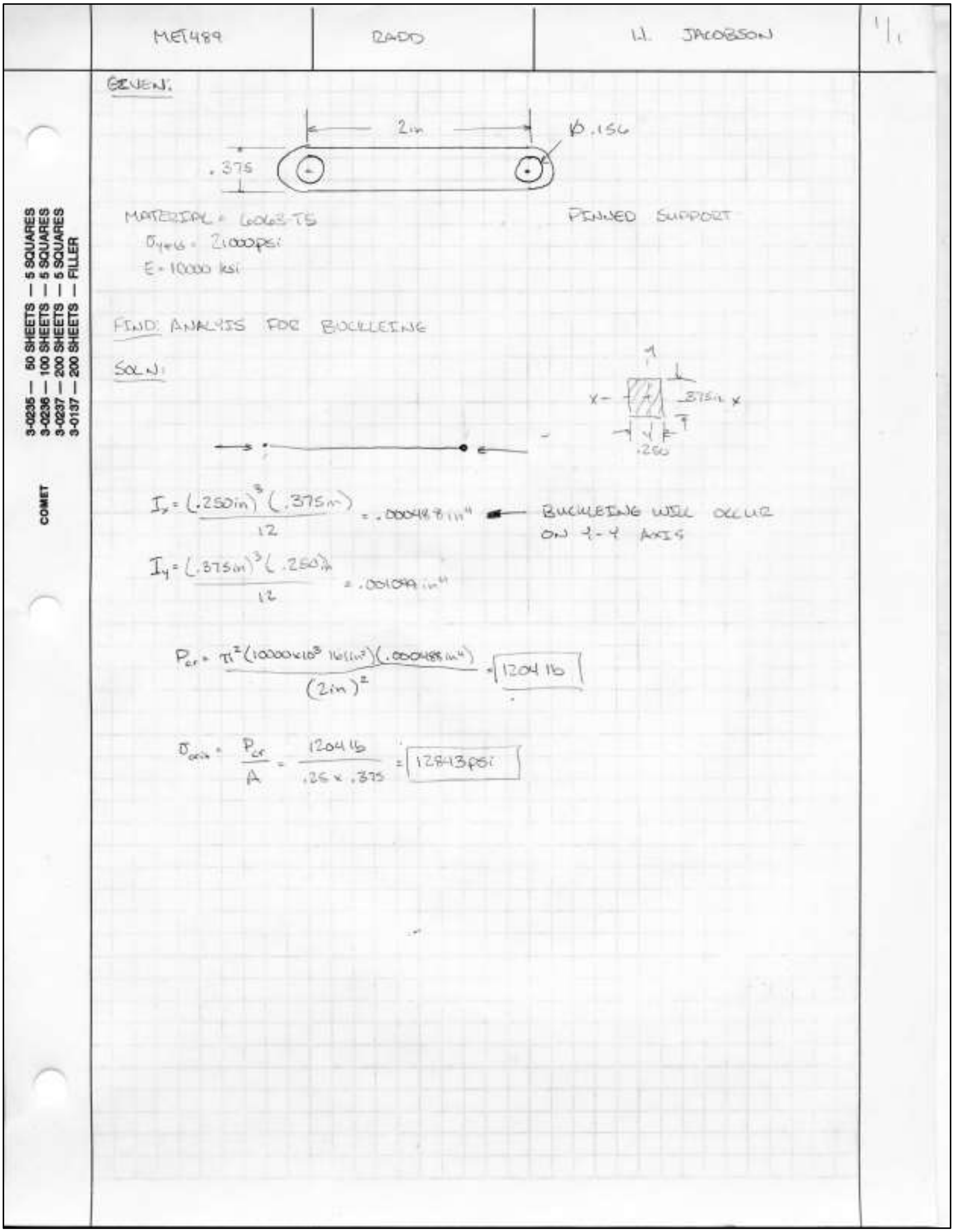


Figure 11 - Analysis of a suspension support link



MET489 | RADD | W. JACOBSON | 1/1

GIVEN:

2 in

Ø.156

.375

MATERIAL = 6063-T5

σ_{yield} = 21000 psi

E = 10000 ksi

PINNED SUPPORT

FIND: ANALYSIS FOR BUCKLING

SOLN:

y

x

.375 in

.250

$$I_x = \frac{(.250in)^3(.375in)}{12} = .000488\,in^4$$ ← BUCKLING WILL OCCUR ON Y-Y AXIS

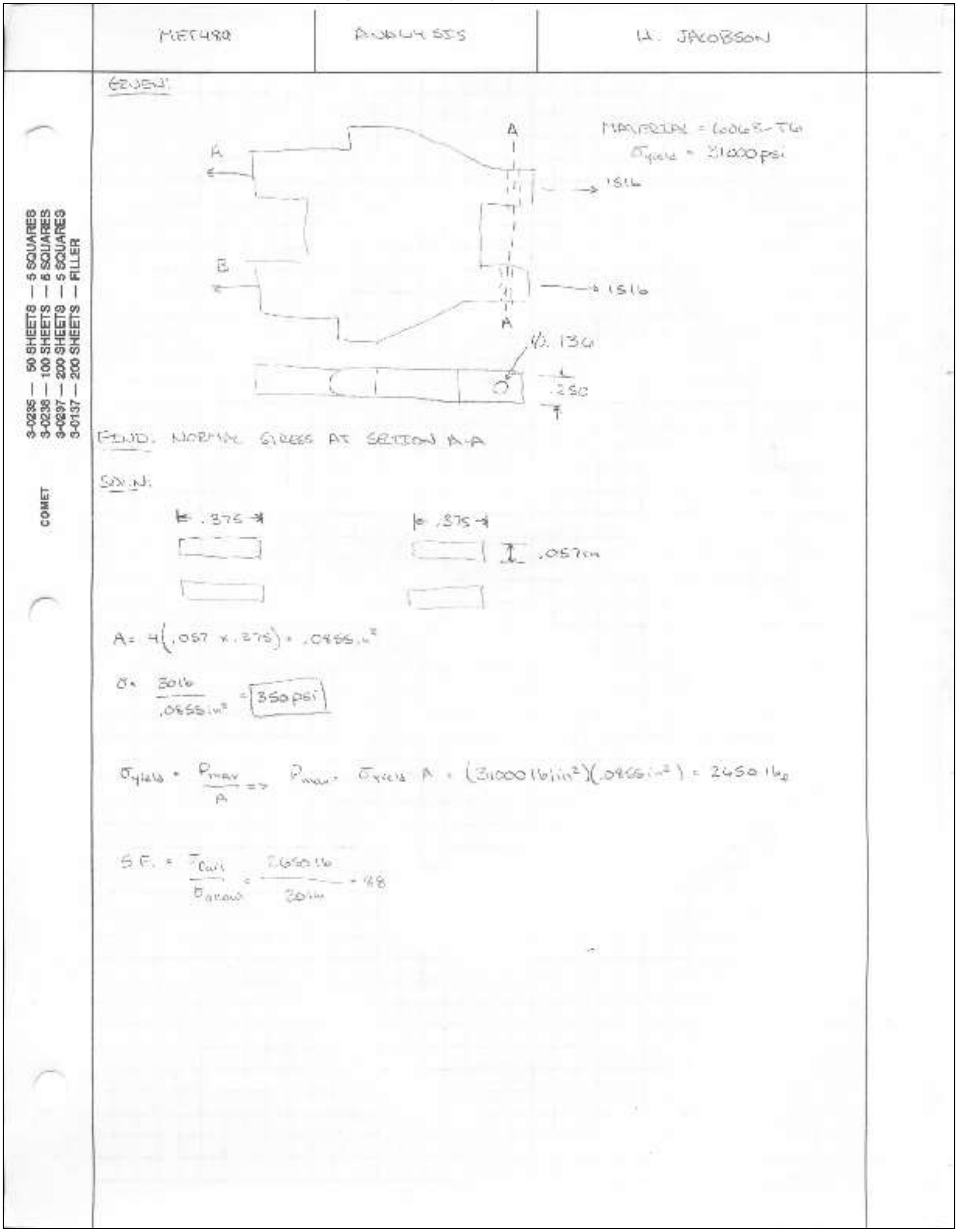
$$I_y = \frac{(.375in)^3(.250in)}{12} = .001099\,in^4$$

$$P_{cr} = \frac{\pi^2(10000\times10^3\,lb/in^2)(.000488\,in^4)}{(2in)^2} = \boxed{1204\,lb}$$

$$\sigma_{crit} = \frac{P_{cr}}{A} = \frac{1204\,lb}{.25\times.375} = \boxed{12843\,psi}$$

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Figure 12 - Analysis of the control arm



MET480 | ANALYSIS | H. JACOBSON

GIVEN:

MATERIAL = 6061-T6

σ_{yield} = 31000 psi

15 lb

15 lb

A

B

A

A

Ø .136

.250

FIND: NORMAL STRESS AT SECTION A-A

SOLN:

.375

.375

.057 in

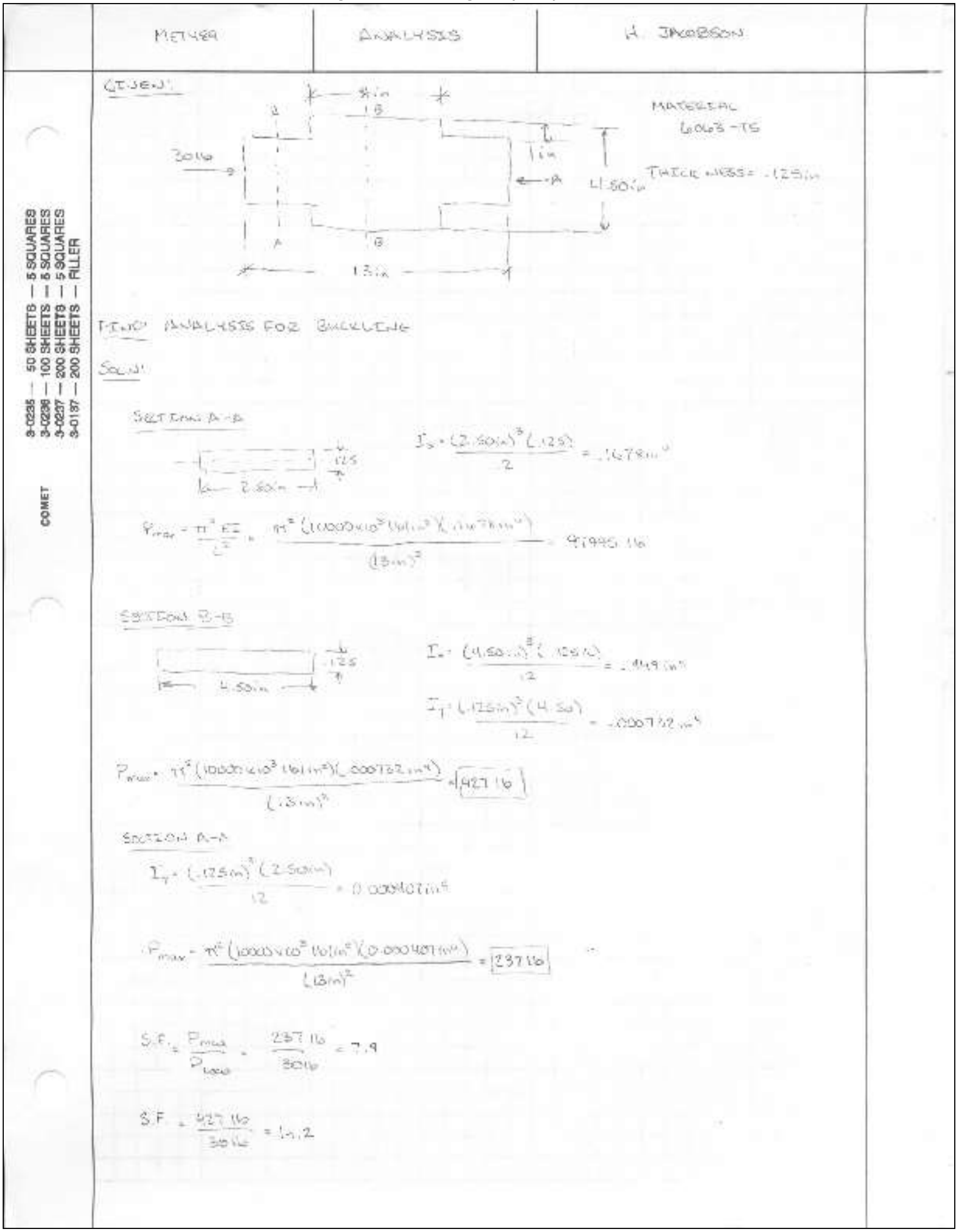
$A = 4(.057 \times .375) = .0855\ in^2$

$\sigma = \dfrac{30\ lb}{.0855\ in^2} = \boxed{350\ psi}$

$\sigma_{yield} = \dfrac{P_{max}}{A} \Rightarrow P_{max} = \sigma_{yield} A = (31000\ lb/in^2)(.0855\ in^2) = 2650\ lb$

$S.F. = \dfrac{\sigma_{fail}}{\sigma_{allow}} = \dfrac{2650\ lb}{30\ lb} = 88$

Figure 13 - Buckling analysis of the base



METR 489	ANALYSIS	H. JACOBSON

GIVEN:

FIND: ANALYSIS FOR BUCKLING

SOL'N:

SECTION A-B

.125
2.50 in

$$I_x = \frac{(2.50in)^3(.125)}{12} = .1628 in^4$$

$$P_{max} = \frac{\pi^2 EI}{L^2} = \frac{\pi^2(10000\times10^3 lb/in^2)(.1628 in^4)}{(13 in)^2} = 95095 lb$$

SECTION B-B

.125
4.50 in

$$I_x = \frac{(4.50in)^3(.125in)}{12} = .949 in^4$$

$$I_y = \frac{(.125in)^3(4.50)}{12} = .000732 in^4$$

$$P_{max} = \frac{\pi^2(10000\times10^3 lb/in^2)(.000732 in^4)}{(13in)^2} = \boxed{427 lb}$$

SECTION A-A

$$I_y = \frac{(.125in)^3(2.50in)}{12} = 0.000407 in^4$$

$$P_{max} = \frac{\pi^2(10000\times10^3 lb/in^2)(0.000407 in^4)}{(13in)^2} = \boxed{237 lb}$$

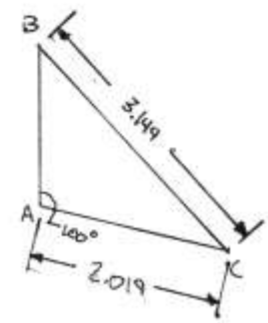
$$S.F. = \frac{P_{max}}{P_{load}} = \frac{237 lb}{30 lb} = 7.9$$

$$S.F. = \frac{427 lb}{30 lb} = 14.2$$

Figure 14 - Location analysis of the holes for the shocks

MET489	SUSPENSION ANALYSIS	H. JACOBSON	1/1

GIVEN:



$L_{AC} = 2.019$ in
$L_{BC} = 3.149$ in
$\angle A = 100°C$

FIND: LENGTH OF B TO C

SOLN:

USE LAW OF SINES AND COSINES

$$\cancel{\frac{a}{\sin A} = \frac{c}{\sin C}} \Rightarrow \cancel{c = \sin C\left(\frac{a}{\sin a}\right)}$$

$$\frac{a}{\sin A} = \frac{b}{\sin B} \Rightarrow \sin B = \frac{b \sin A}{a} = \frac{(2.019 \text{ in})(\sin 100°)}{3.149}$$

$\sin B = .631415$

$B = \arcsin(.631415) = 39.15°$

$A + B + C = 180° \Rightarrow C = 180° - 39.15° - 100° = 40.85°$

$$\frac{a}{\sin a} = \frac{c}{\sin c} \Rightarrow C = \sin c\left(\frac{a}{\sin a}\right) = \sin(40.85°)\left(\frac{3.149 \text{ in}}{\sin(100°)}\right) = \boxed{2.091 \text{ in}}$$

SUSPENSION PIN NEEDS TO BE .523 in FROM TOP OF UPPER SUPPORT

Figure 15 - Impact force analysis of the RC Baja Car

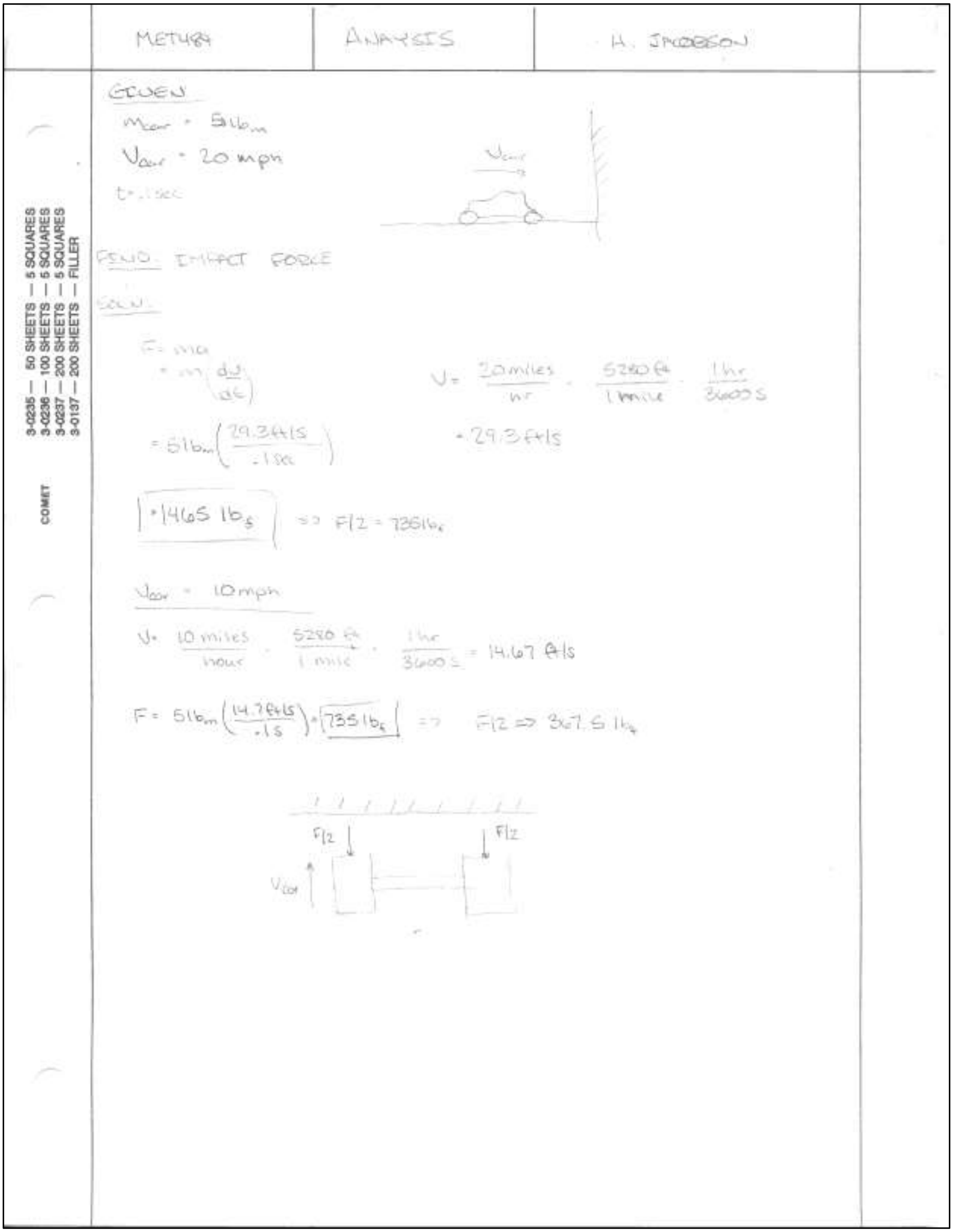
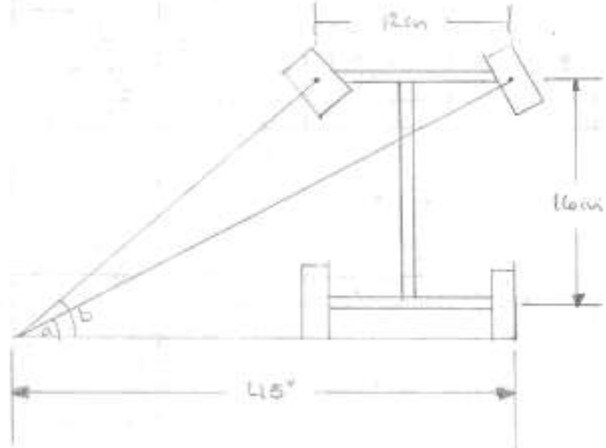


Figure 16 - Ackermann Steering Geometry analysis

H. JACOBSON	MET4808	ACKERMAN ANGLE	1/1

GIVEN:

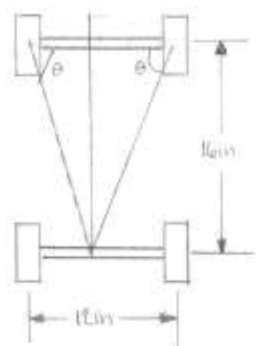


FIND: ACKERMAN GEOMETRY

SOLN:

$$\tan a = \left(\frac{16\text{in}}{45\text{in}}\right) \Rightarrow a = \arctan\left(\frac{16\text{in}}{45\text{in}}\right) = \boxed{19.57^\circ}$$

$$\tan\theta = \left(\frac{16\text{in}}{6\text{in}}\right) \Rightarrow \theta = \boxed{69.4^\circ}$$



INSIDE TURN RADIUS = 45" − 12" = 33"

$$\tan b = \left(\frac{16''}{33''}\right) \Rightarrow b = \arctan\left(\frac{16''}{33''}\right)$$

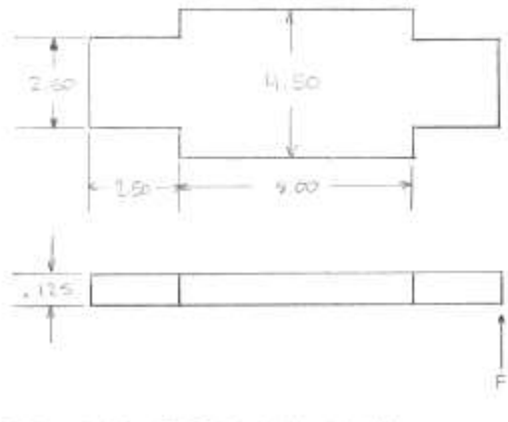
$$\boxed{b = 25.9^\circ}$$

Figure 17 - Bending analysis of the base

METHERA	ANALYSIS	M. JACOBSON	A

GIVEN: IMPACT ON CHASSIS PLATE

thickness: .125"
aluminum 6063-T5
$S_u = 35000$ lb/in²
$S_y = 21000$ psi
$E = 10000$ ksi



FIND: BENDING STRESS ON PLATE

SOLN:

INSTANCES WHERE CHASSIS PLATE CAN BE CONTACTED DIRECTLY
- OBJECT THINNER THAN WHEELBASE CONTACTS PLATE
- SHOCKS COMPRESS ENTIRELY, REMAINING FORCE TRAVELS THROUGH CHASSIS
- FORWARD IMPACT ON RC CAR

VELOCITY AFTER FALLING 1 FOOT

$mgh = \frac{1}{2}mv^2$
$gh = \frac{1}{2}v^2$
$2gh = v^2$
$\sqrt{2gh} = v = \sqrt{2(32.2\ ft/s^2)(1\ foot)} = 8.02\ ft/s$

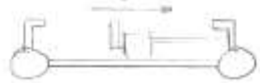
IMPACT FORCE

$F = (5\ lb_m)\left(\frac{8.02\ ft/s}{.1\ s}\right) = 401\ \frac{lb_m\text{-}ft}{s^2}\left(\frac{1\ lb_f}{32.174\ lb_m\text{-}ft/s^2}\right) = 12.5\ lb_f$

Figure 18 - Bending analysis of the plate while in motion

METH8491A	ANALYSIS	H. JACOBSON	A

IMPACTS OBJECT AT 20MPH



$$\frac{20\text{ miles}}{1\text{ hour}} \cdot \frac{5280\text{ ft}}{1\text{ mile}} \cdot \frac{1\text{ hour}}{3600\text{ sec}} = 29.3\text{ ft/s}$$

$$F = (5\,lb_m)\left(\frac{29.3\text{ ft/s}}{.1\text{ s}}\right) = 1465\,\frac{lb_m \cdot ft}{s^2}\left(\frac{1\,lb_f}{32.174\,lb_m \cdot ft/s^2}\right)$$

$$= 45.5\,lb_f$$

FORCES WILL LIKELY BETWEEN 12 lb_f TO 46 lb_f. DESIGNING FOR 55 lb_f WOULD GIVE 1.21 SAFETY FACTOR.

MOMENTS OF INERTIA

$$I = \frac{(2.50\text{ in})(.125\text{ in})^3}{12} = .00041\text{ in}^4$$

DESIGN FOR LOWEST MOMENT OF INERTIA

$$I = \frac{(4.50\text{ in})(.125\text{ in})^3}{12} = .00073\text{ in}^3$$

BENDING STRESS

$$\sigma = \frac{My}{I} = \frac{(55\,lb_f)(13\text{ in})(.0625\text{ in})}{.00041\text{ in}^4} = \boxed{108994\text{ lb/in}^2}$$

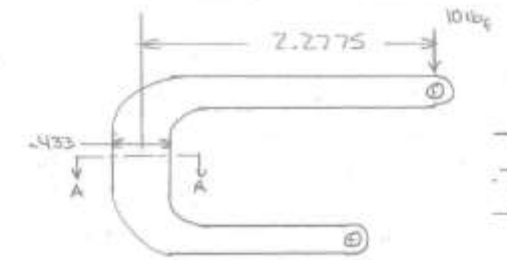
$\sigma > S_y$ ∴ REDESIGN REQUIRED

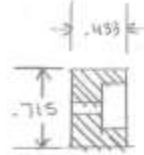
Figure 19 - Analysis of the rear hub carrier

MET 489	ANALYSIS	H. JACOBSON

GIVEN:

$\sigma_{yield} = 3000psi$

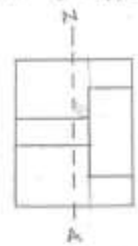




FIND: STRESS AT HOLE

SOLN:

$\sigma = \frac{My}{I}$ $\qquad M = (10 lb_f)(2.2755 in) = 22.775\ lb\text{-}in$



$$I = 2\Big((1/3)(.255in)(.2165in)^3 + (1/3)(.255in)(.0595in)^3 + (1/3)(.141in)(.157in)^3 + (.141)(.157)(.0595)^2\Big)$$

$$= .00228\ in^4$$

$$\sigma = \frac{(22.775 lb\text{-}in)(.2165in)}{.00228in^4} = \boxed{2162\ lb/in^2}$$

$$S.F. = \frac{\sigma_{max}}{\sigma_{allow}} = \frac{3000psi}{2162psi} = 1.38$$

Appendix B – Drawings

ALL DRAWINGS NOT TO SCALE

Figure 20 - Drawing of the lower control arm

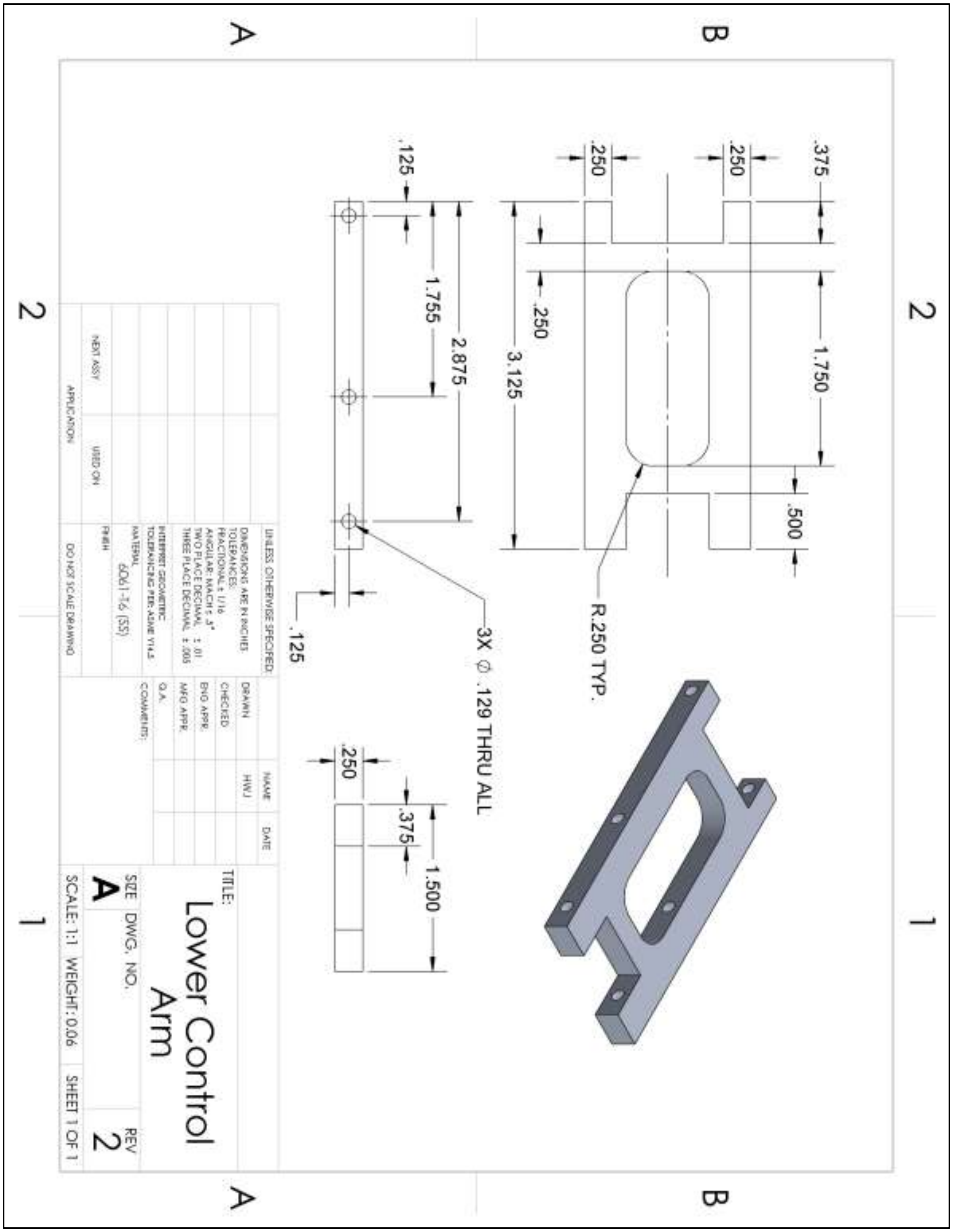


Figure 21 - Drawing of the suspension support

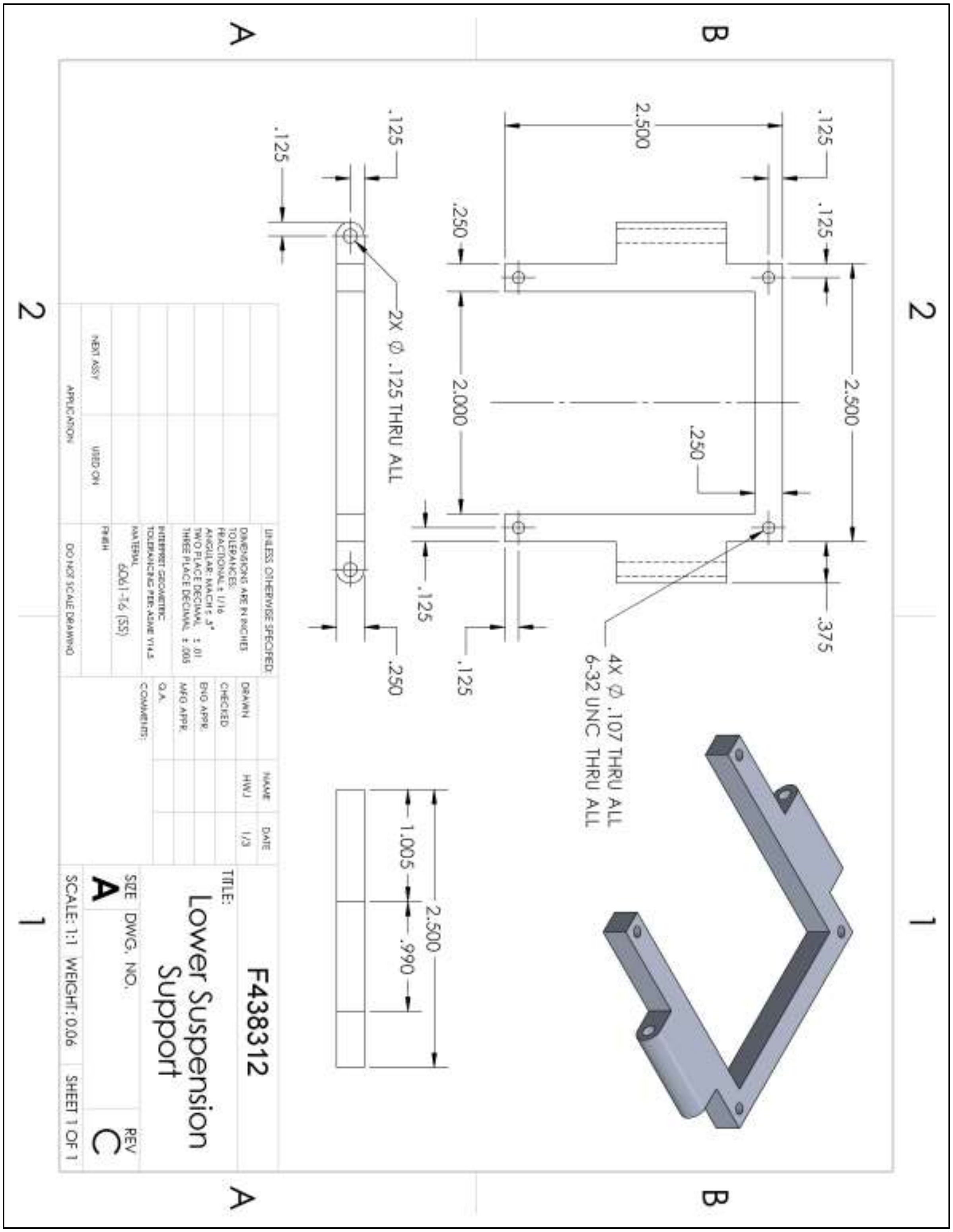


Figure 22 - Drawing of the camber link

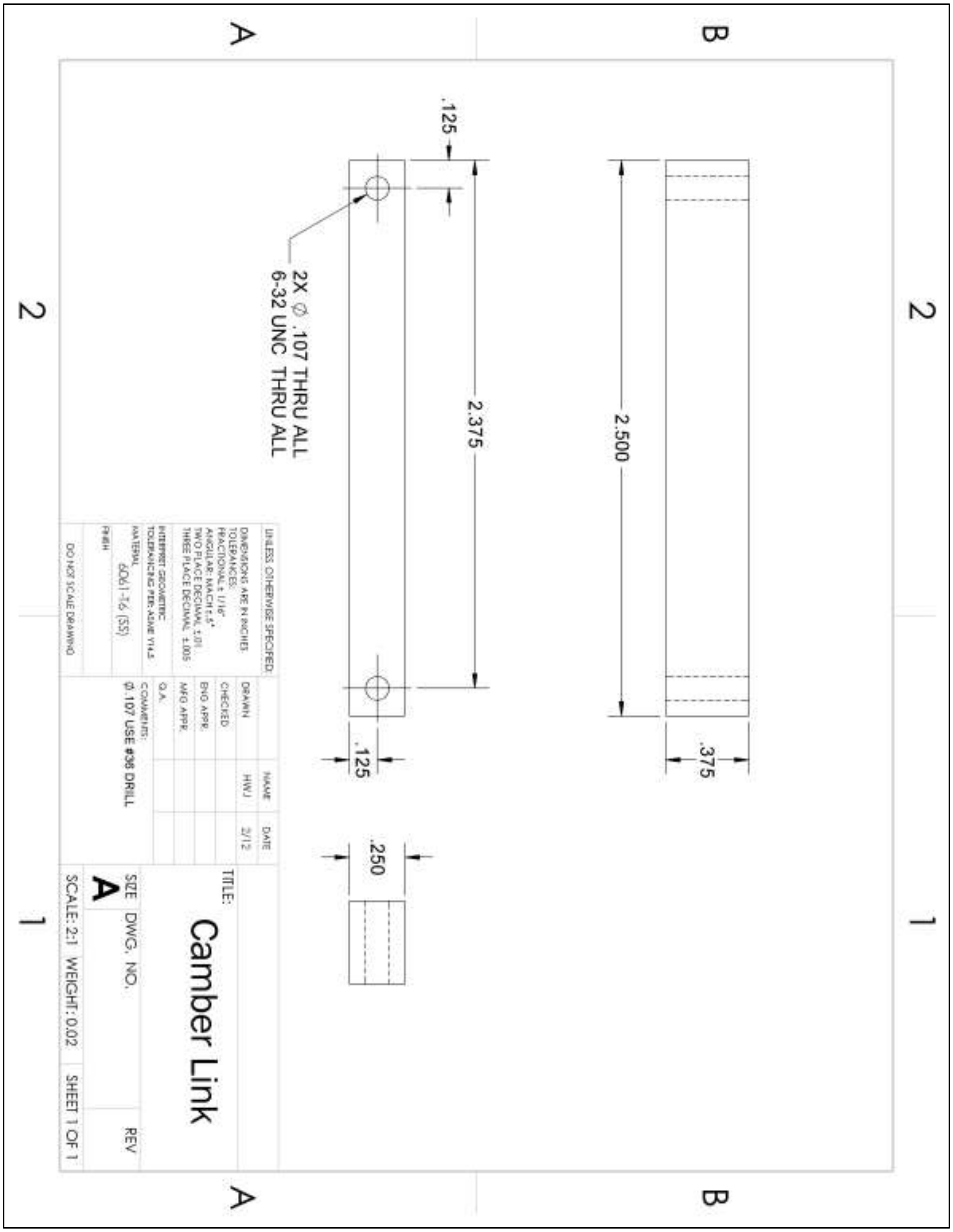


Figure 23 - Drawing of the caster block

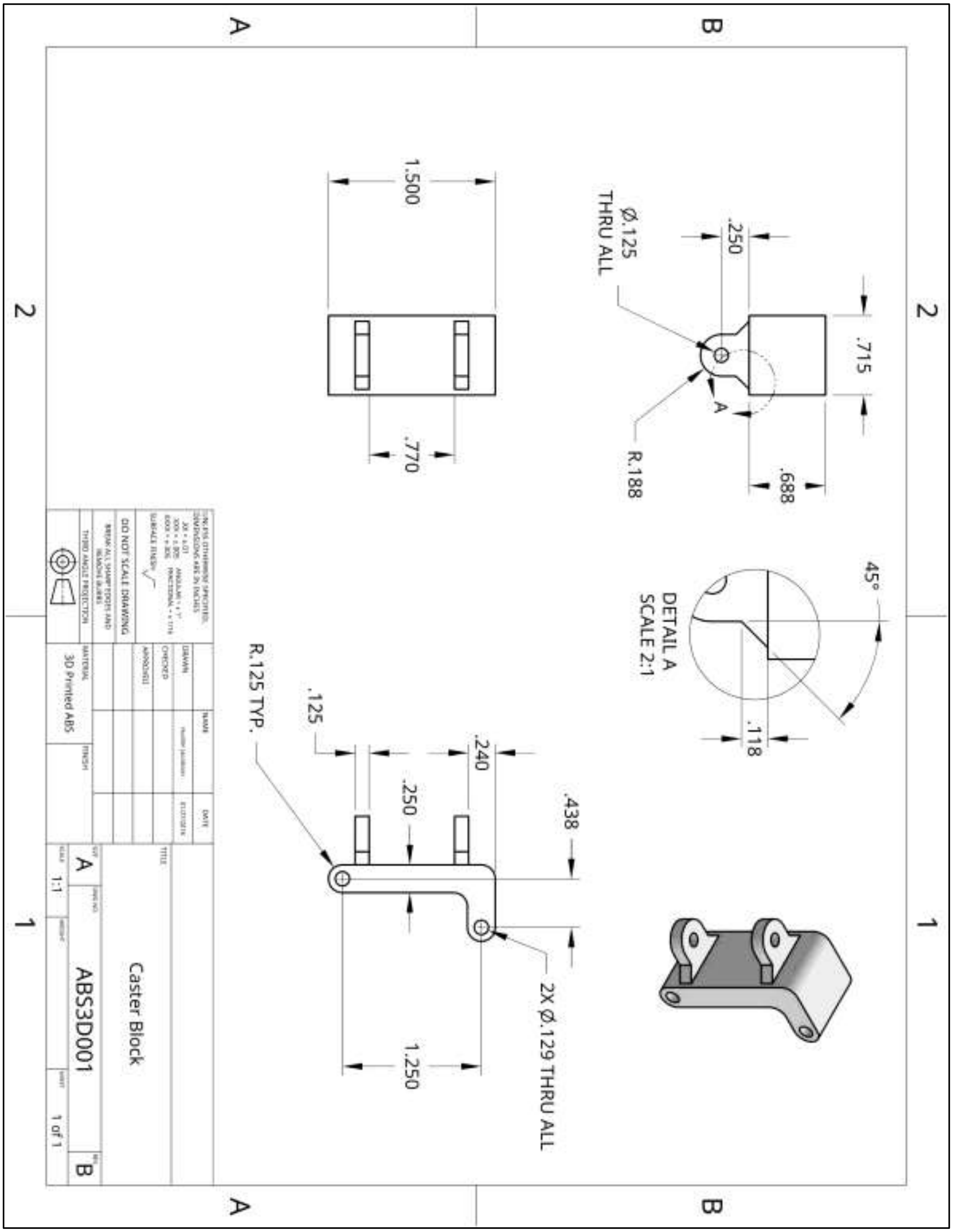


Figure 24 - Drawing of the shock tower

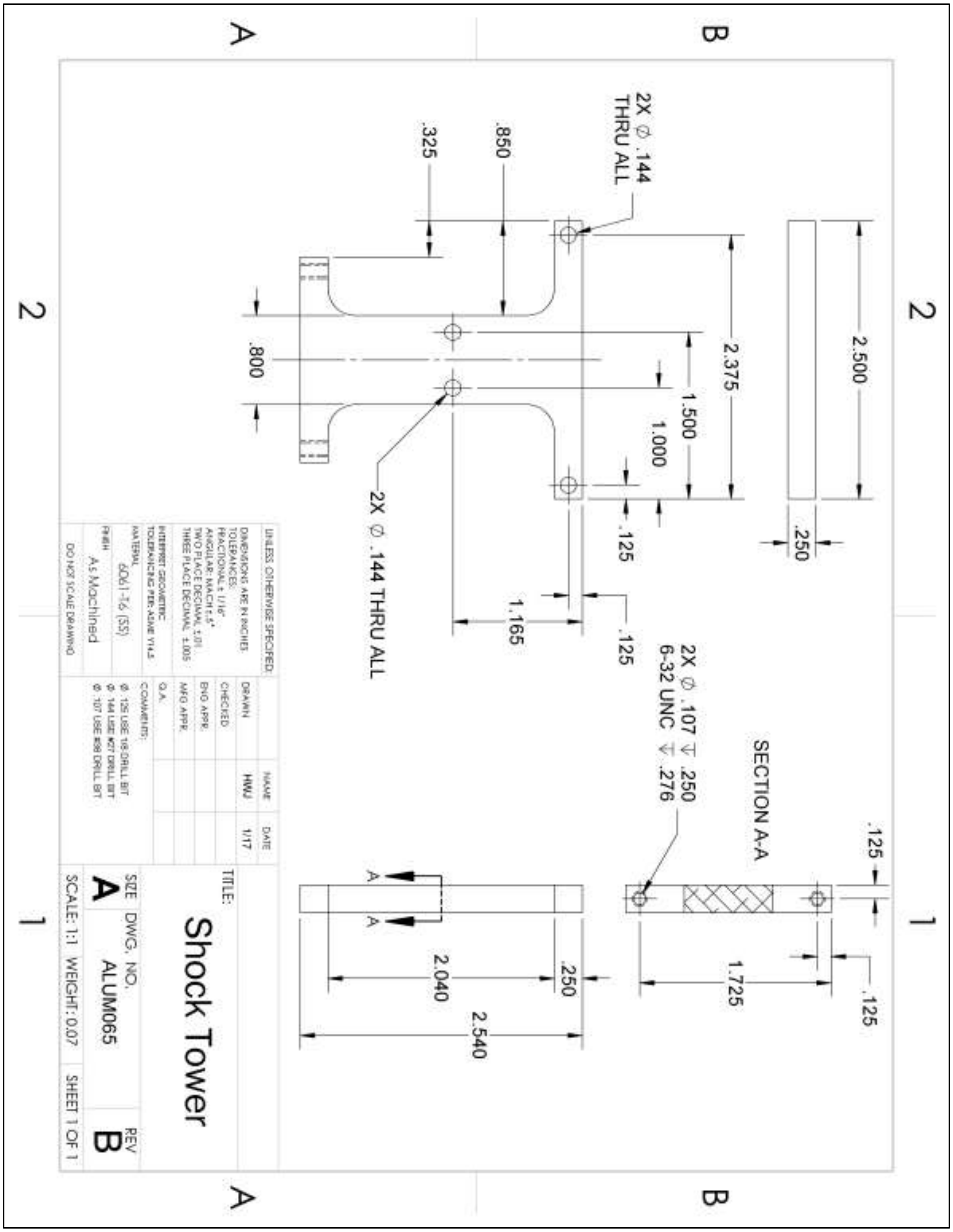


Figure 25 - Drawing of the upper control arm

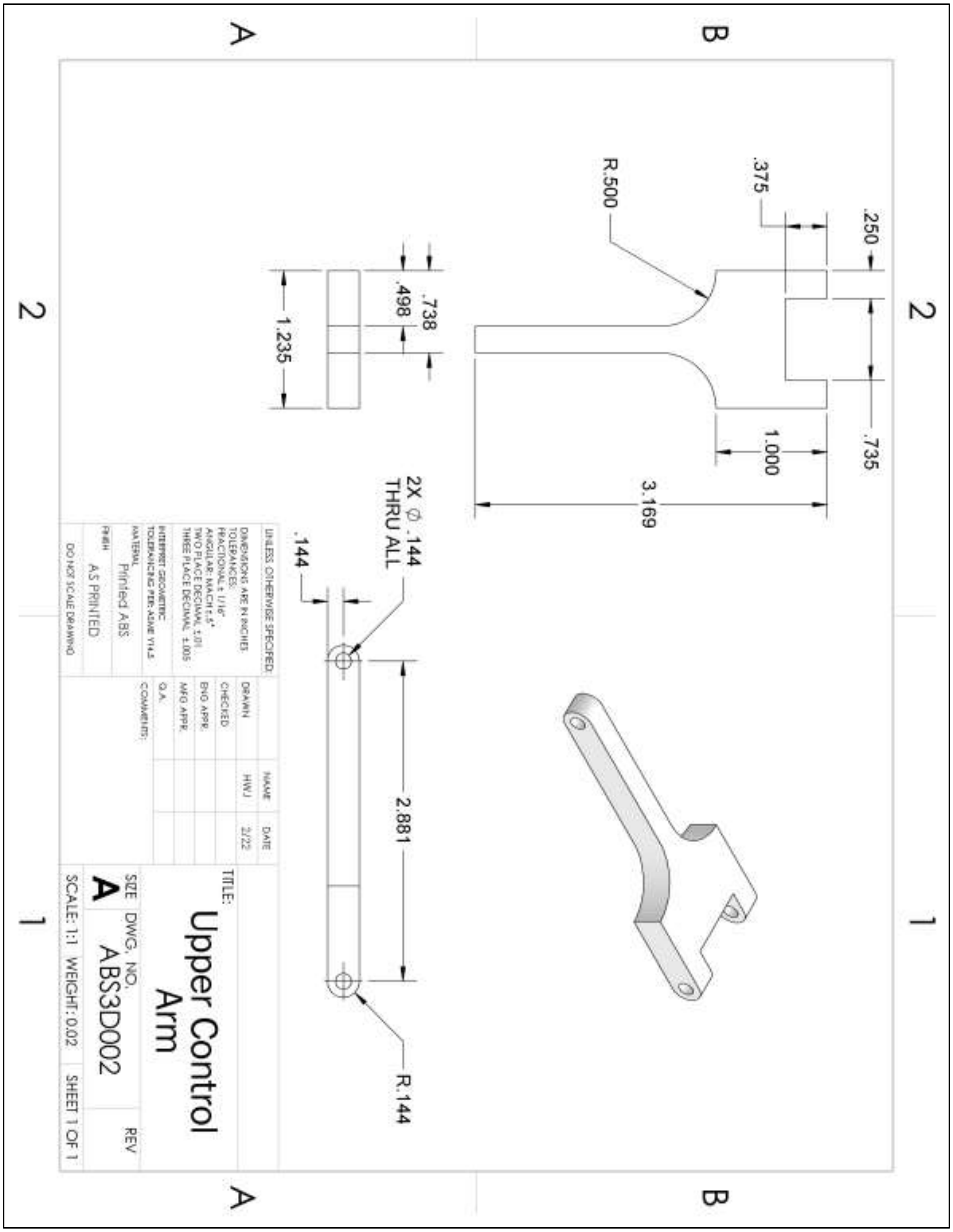


Figure 26 - Drawing of the servo

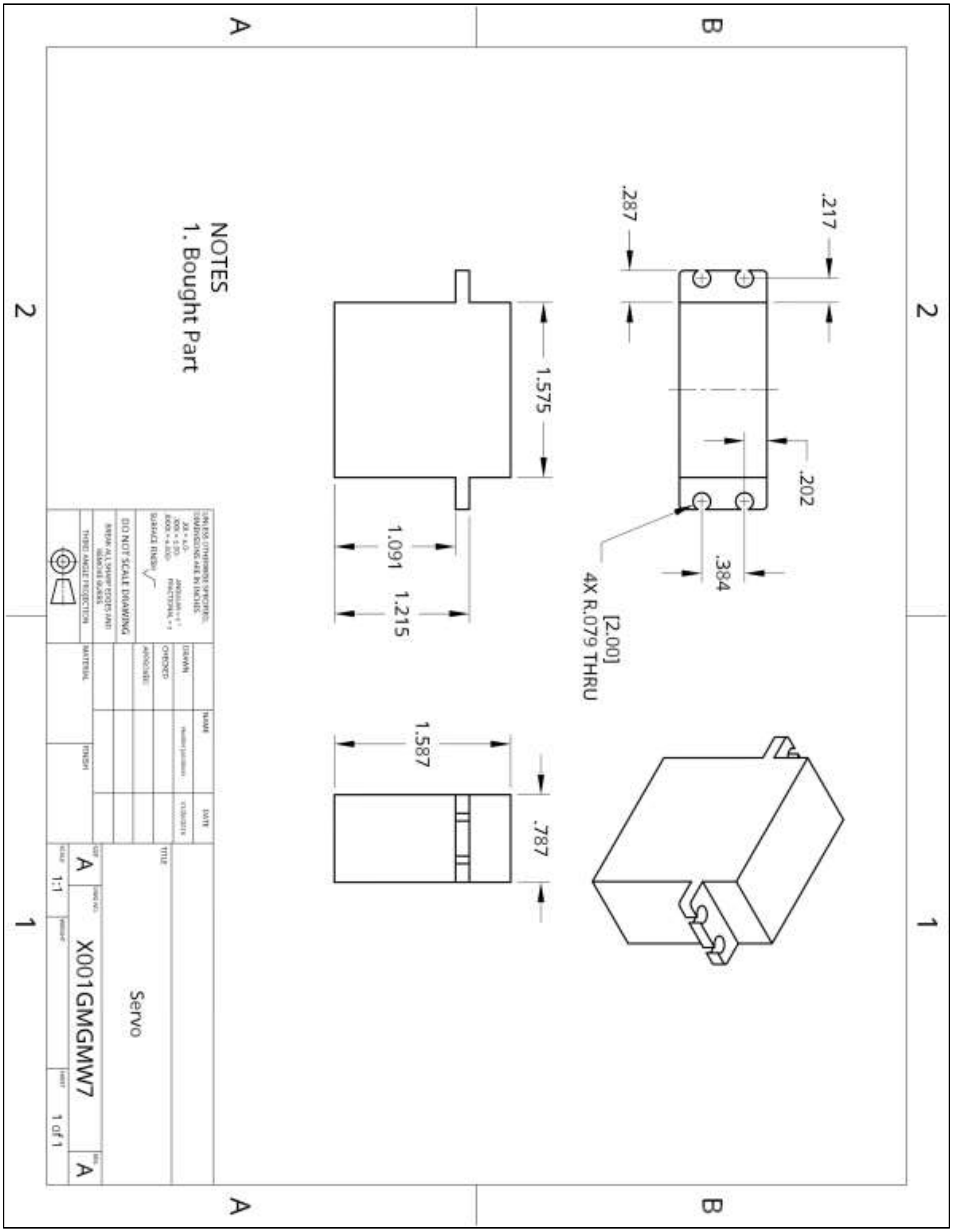


Figure 27 - Drawing of the servo mount

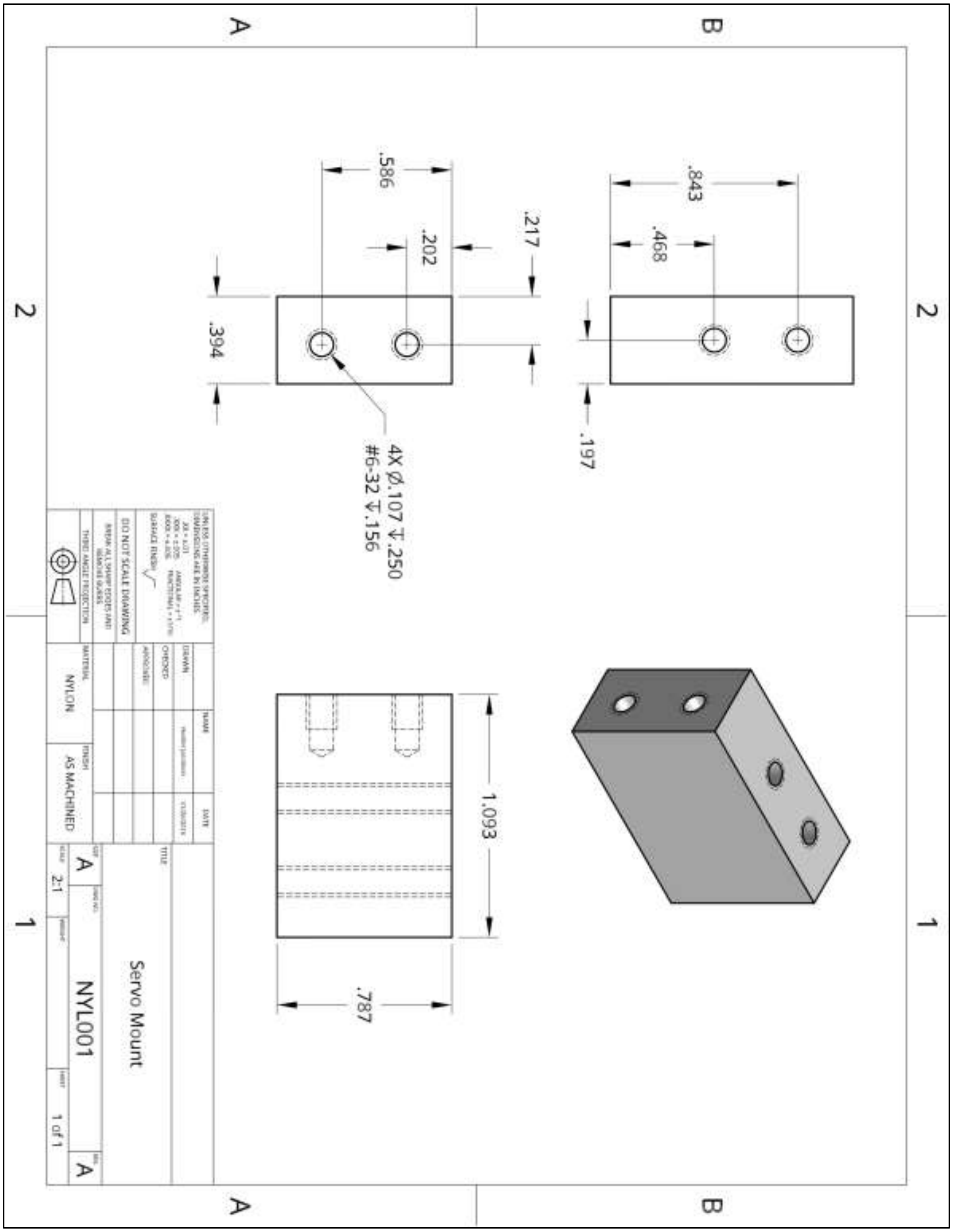


Figure 28 - Drawing of the steering knuckle

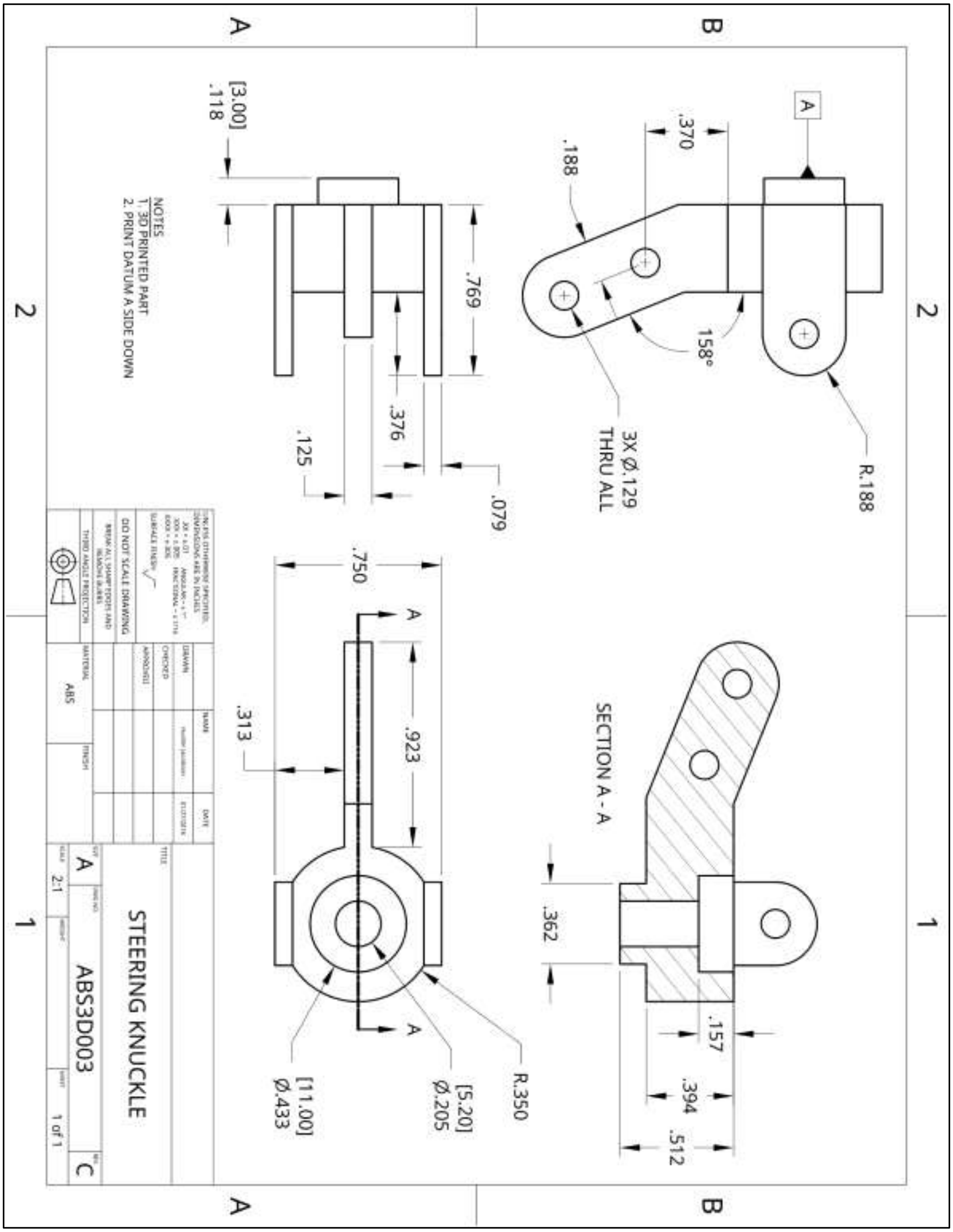


Figure 29 - Drawing of the rear hub carrier

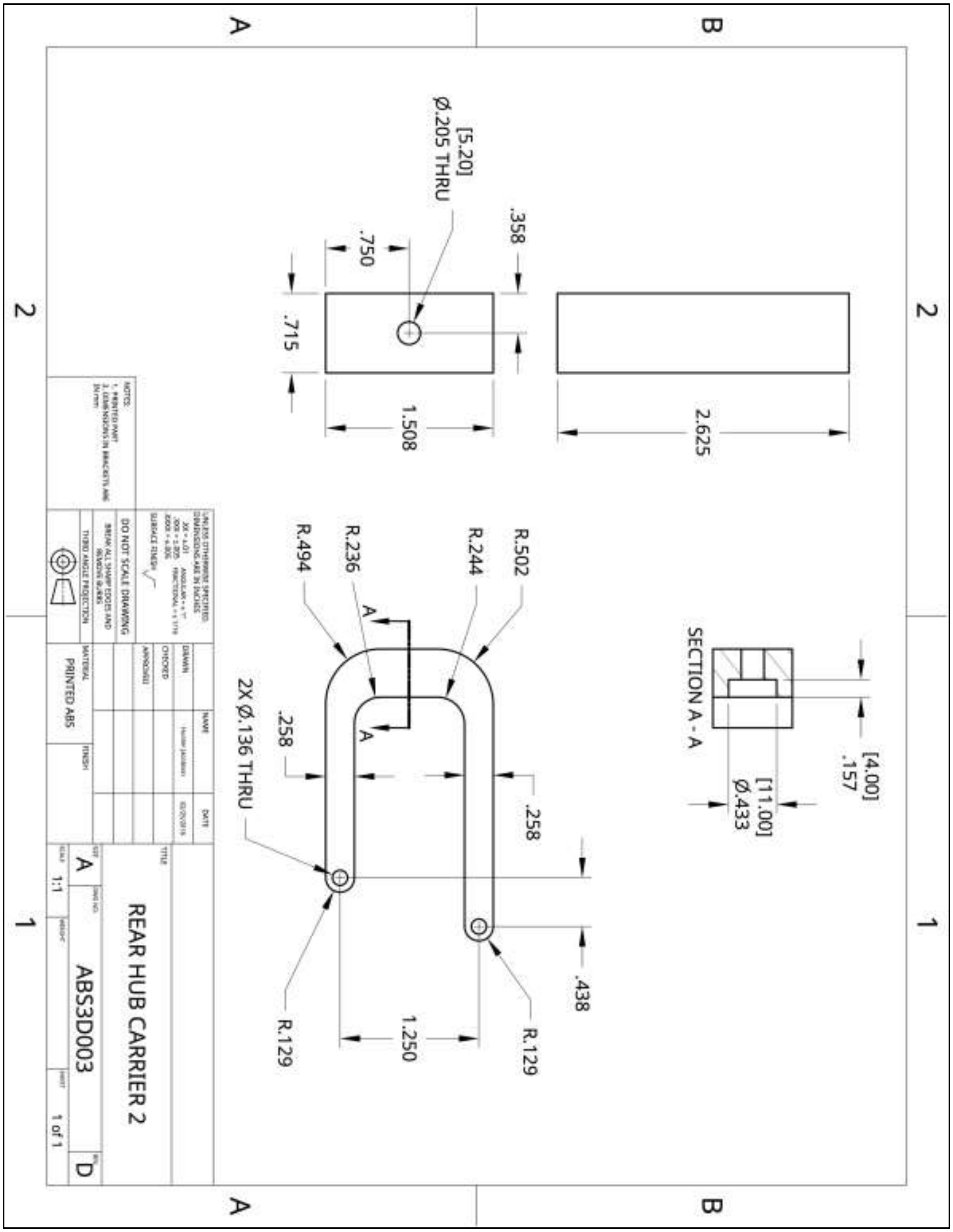


Figure 30 - Drawing of the chassis plate (Sheet 1)

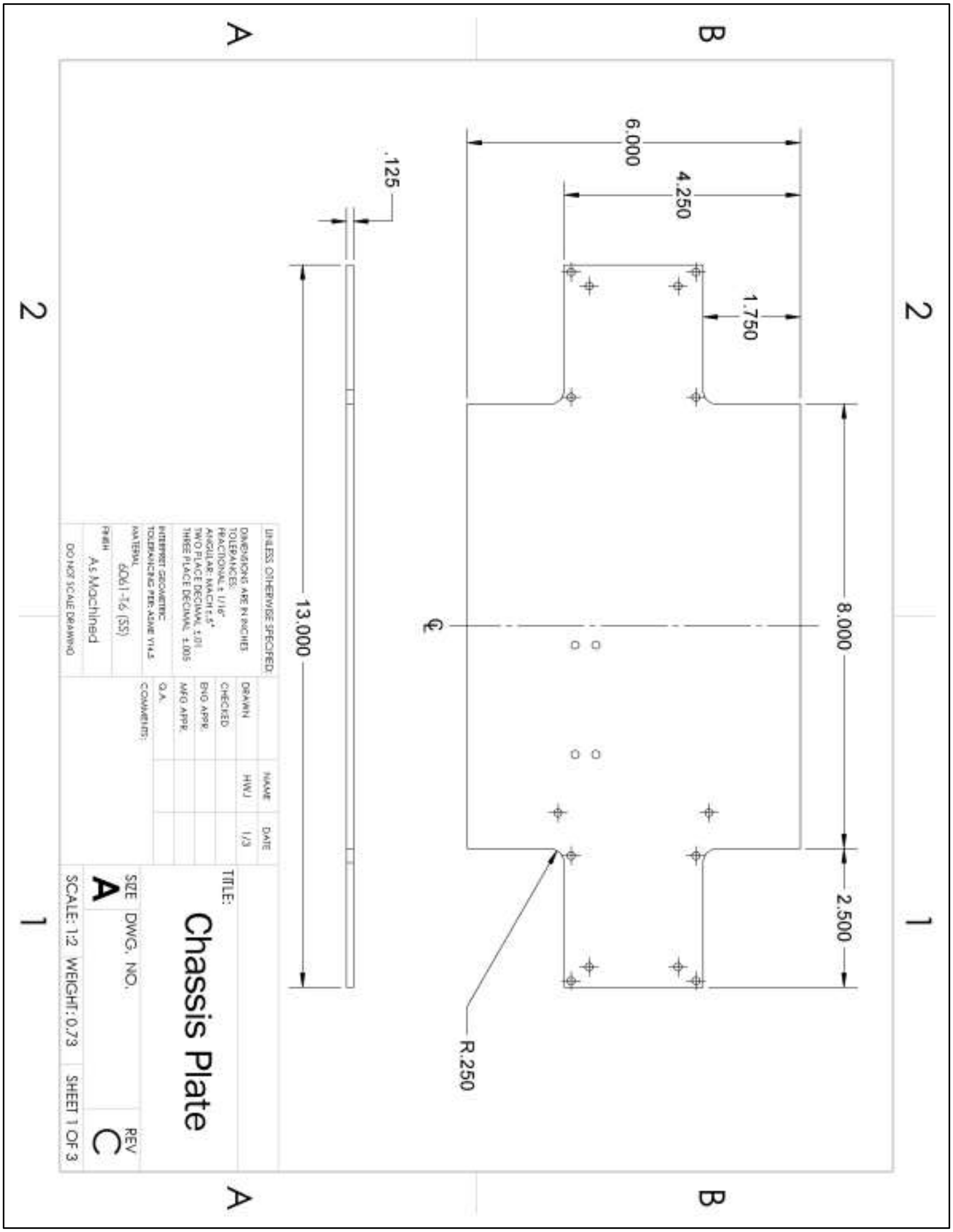


Figure 31 - Drawing of the chassis plate (Sheet 2)

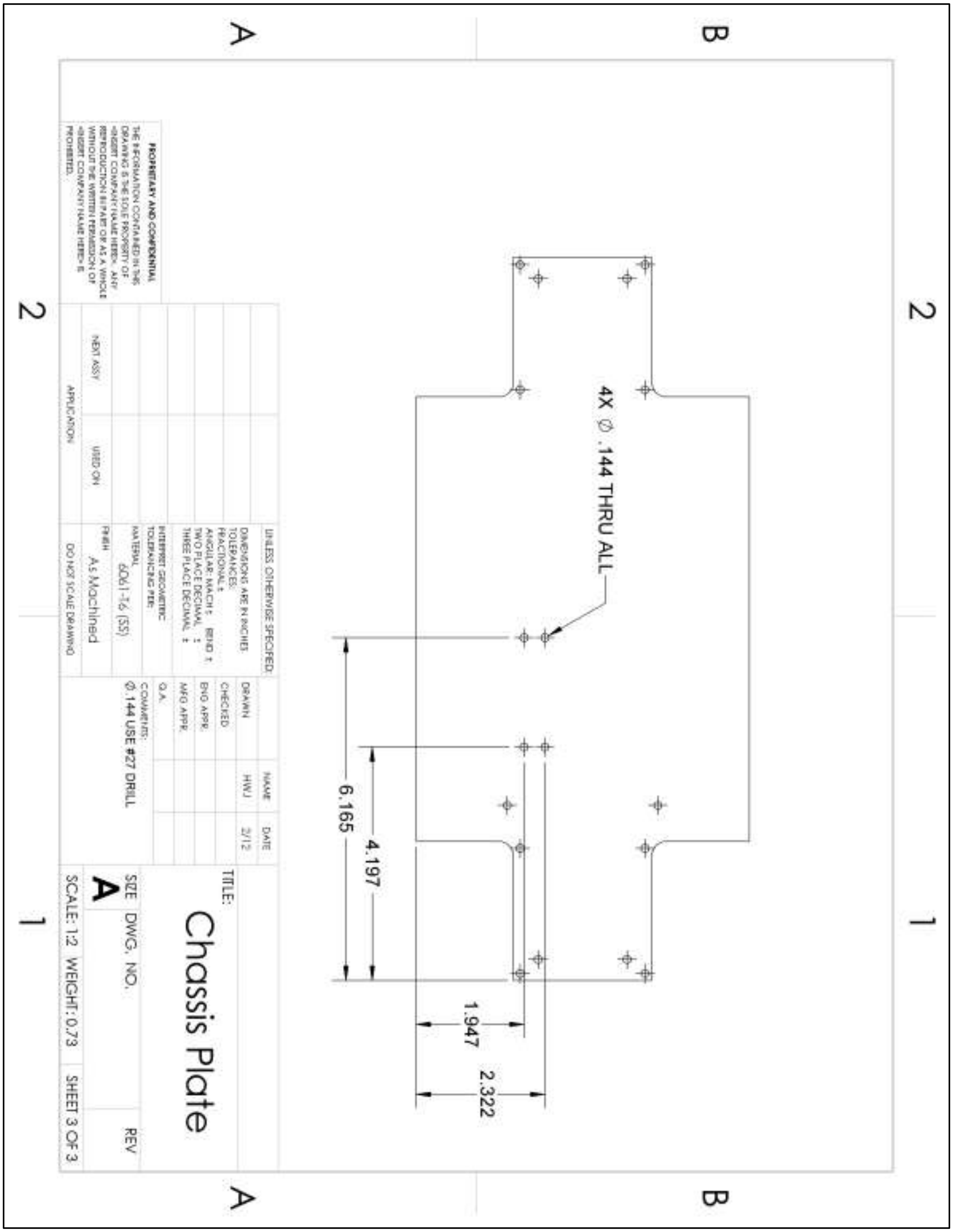


Figure 32 - Front isometric view of the suspension

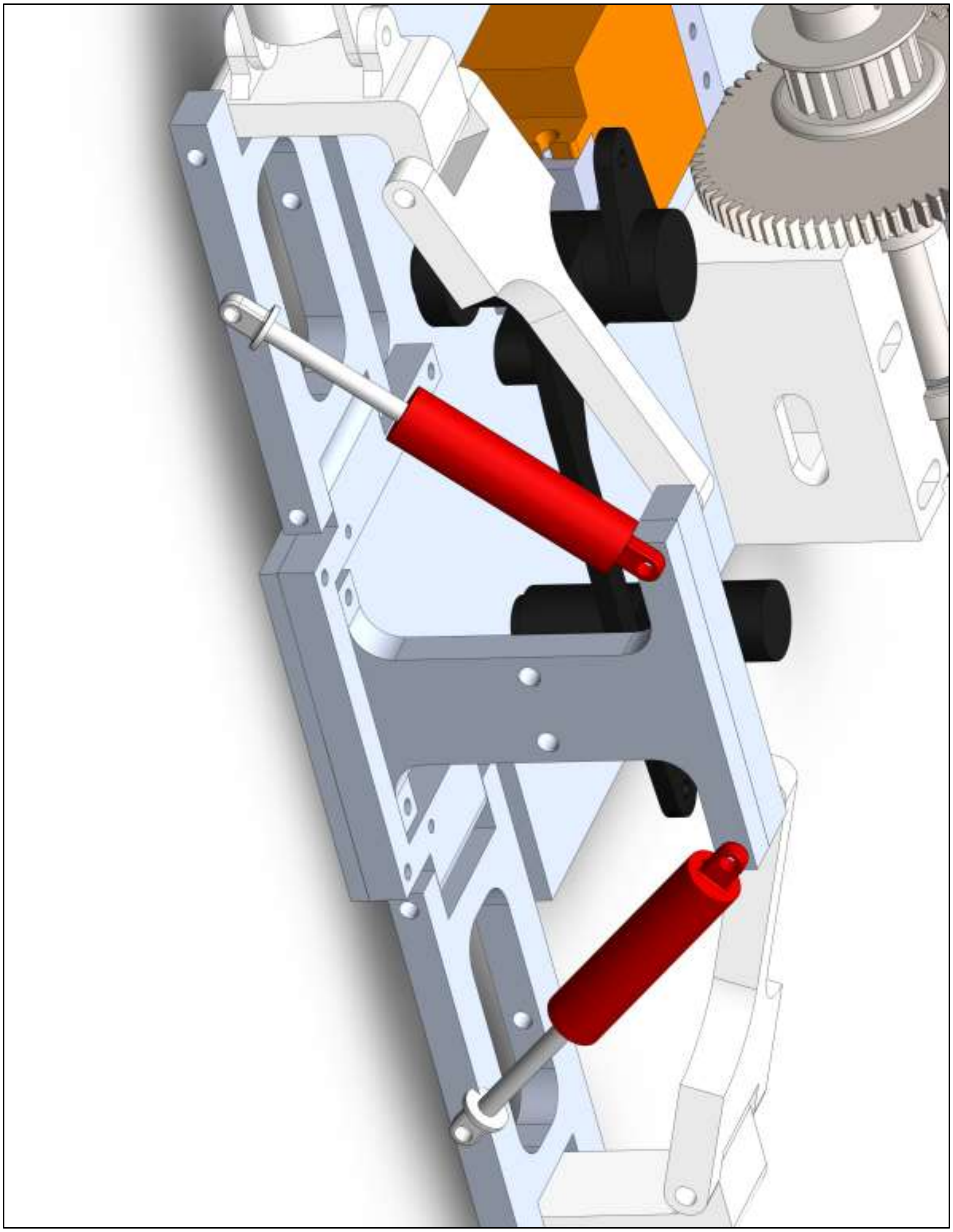


Figure 33 - Rear isometric view of the suspension

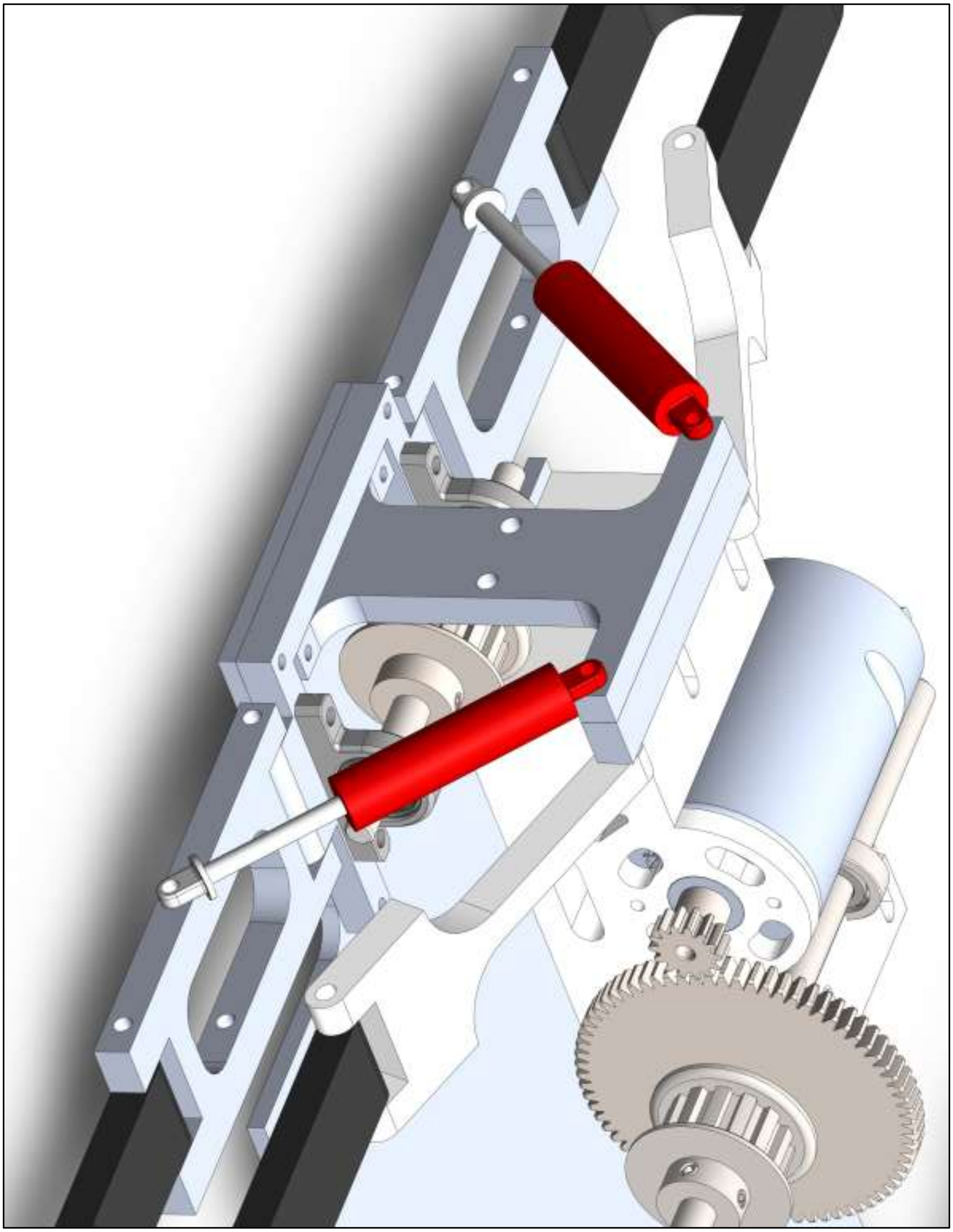


Figure 34 - Reference drawing of the RC Baja Car assembly

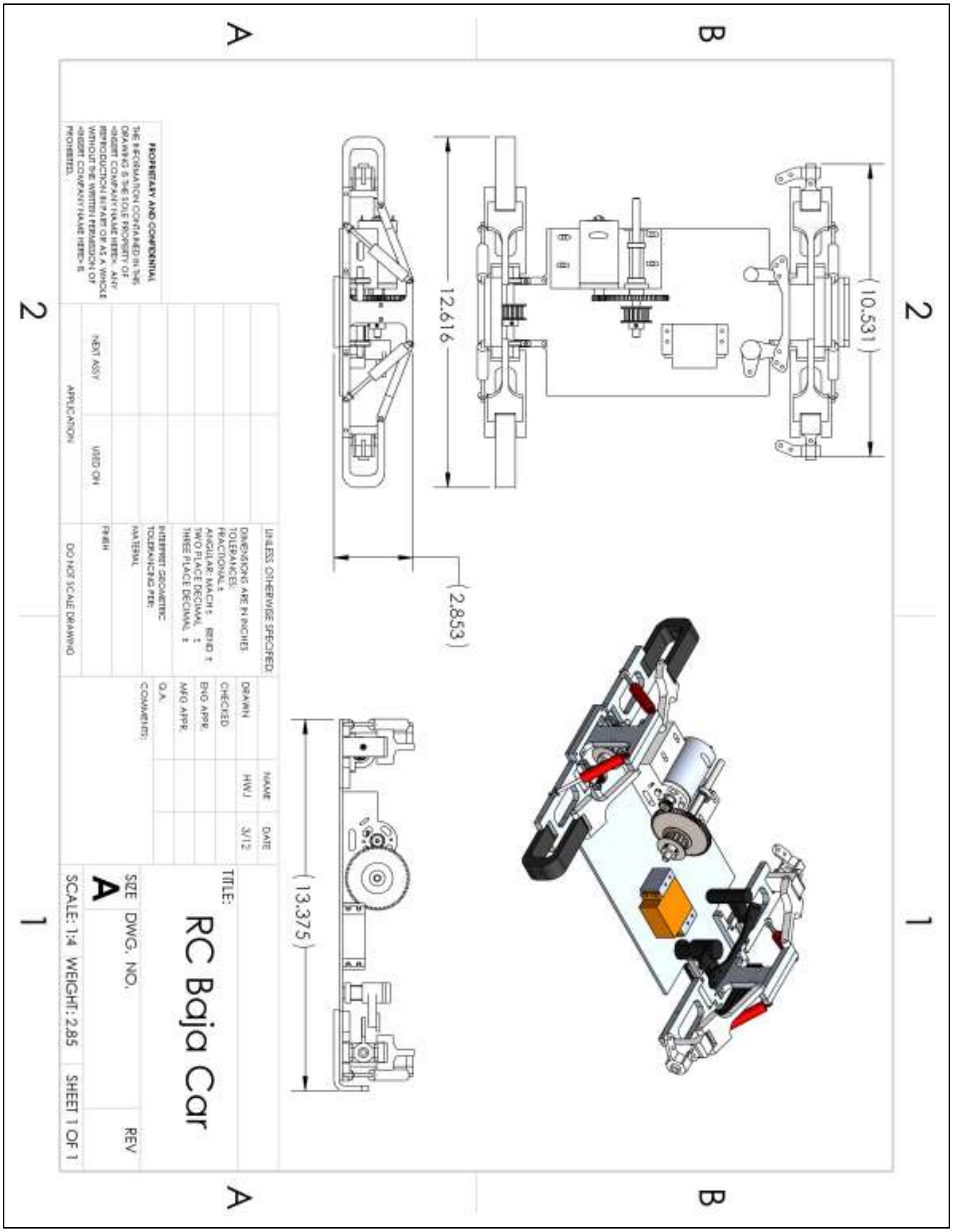


Figure 35 - BOM drawing of the RC car

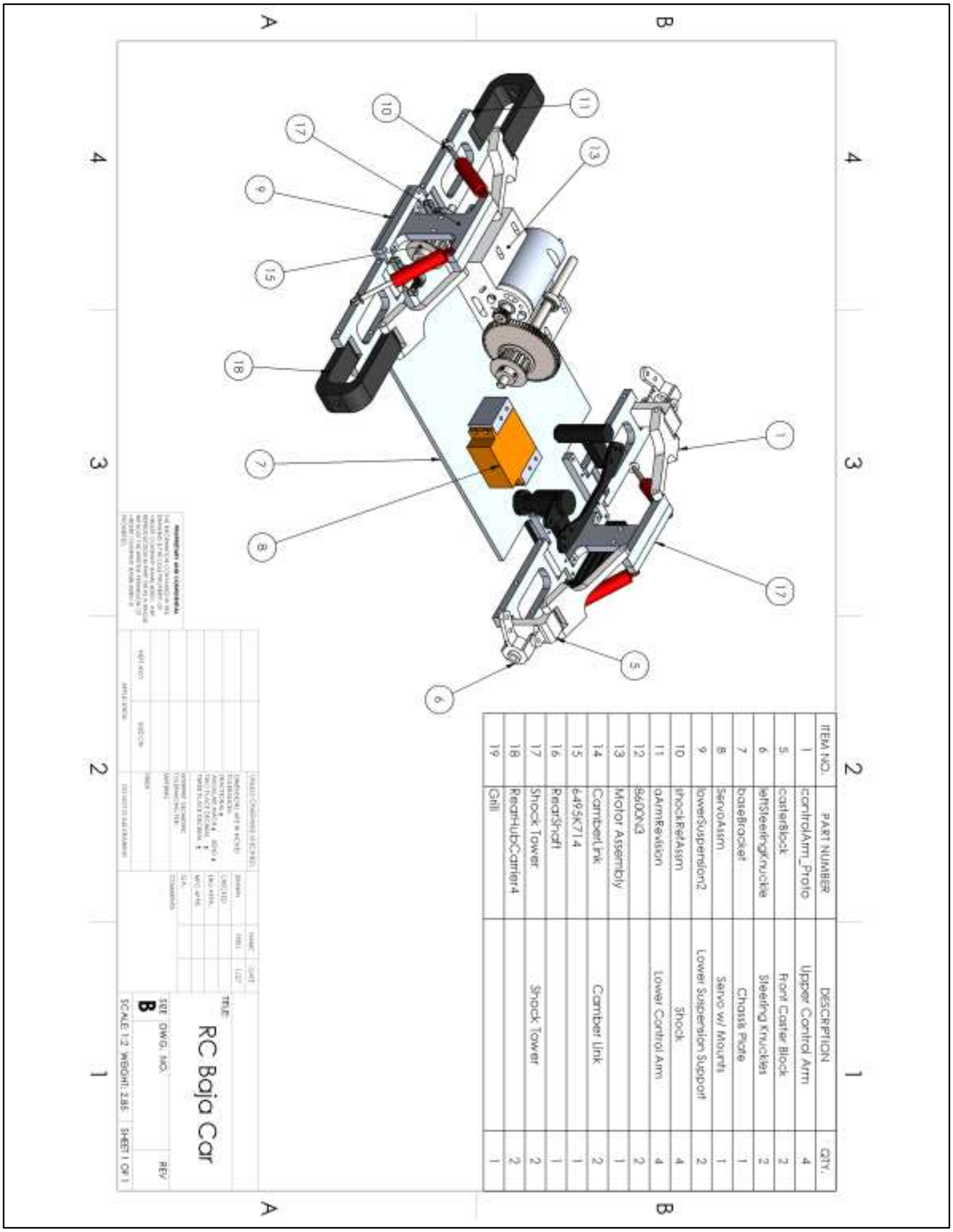
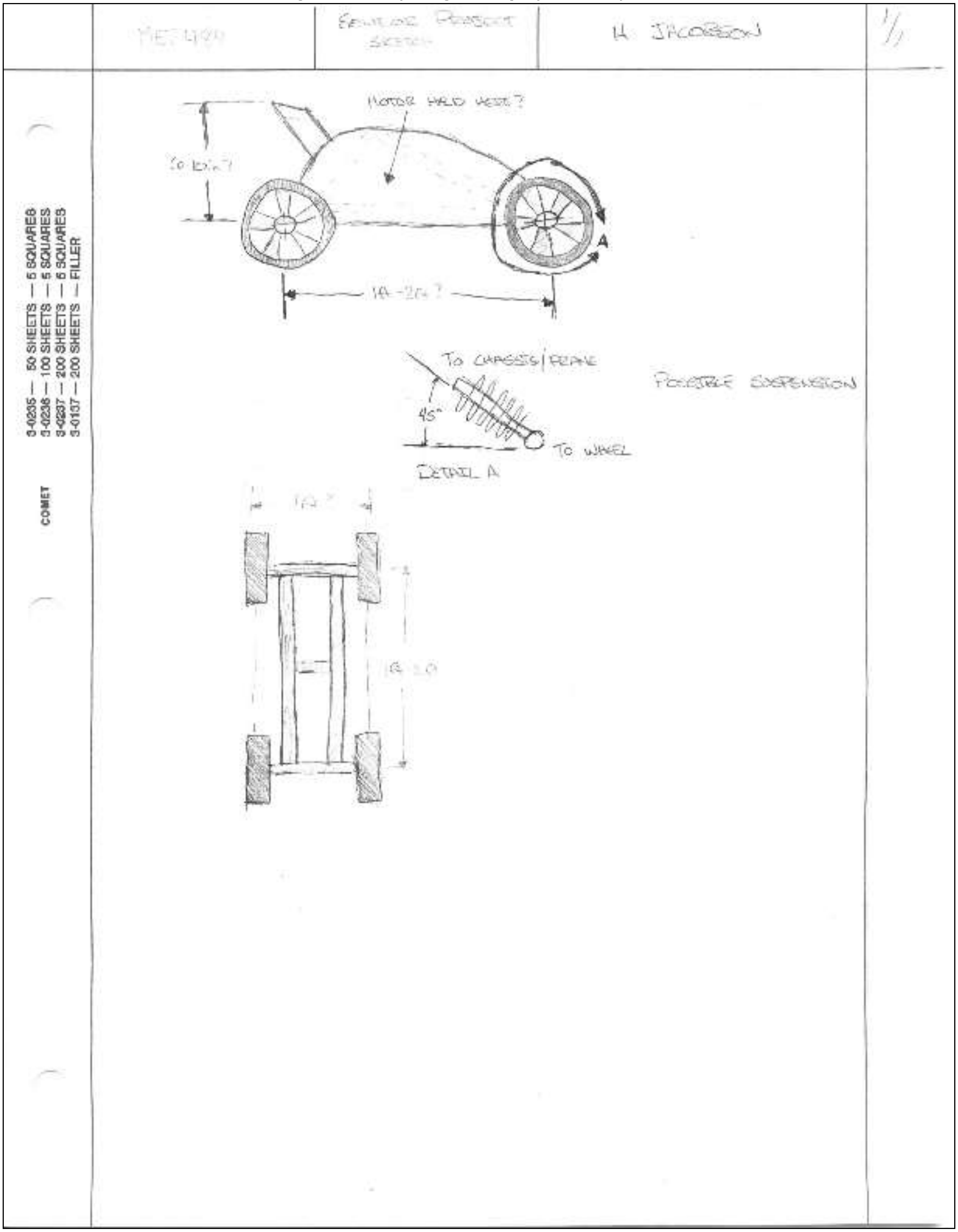


Figure 36 - Early design concept of the RC Baja Car



Appendix C – Parts List, Costs and Budget

Table 1 - Parts List

Vendor ID	Part Number	Part Name	Raw Material and Source	Estimated Cost	Actual Cost	Quantity	Total Cost
F438212	ALUM01	A-Arm	36-1/4" x 4" x 1/4" Alum. Flat Bar (Cut2Size)	$ 45.00	$ 30.32	1	$ 30.32
F438212	ALUM02	Shock Tower					
F438212	ALUM03	Caster Block Mount					
F438212	ALUM04	Suspension Mount					
S318T6	ALUM05	Base Plate	1/8" x 14" x 14" 6061-T6 Alum. Sheet (Cut2Size)	$ 30.00	$ 24.74	1	$ 24.74
KYO33001B	STR01	Suspension Pins	Dollar Hobbyz	$ 20.00	$ 21.99	1	$ 21.99
TRA3740	STR02	King Pins	RC Planet	$ 5.00	$ 2.49	1	$ 2.49
B073F92G2S	STR03	Servo	Amazon	$ 20.00	$ 17.99	1	$ 17.99
YEA-DDL-090OR	SUS01	Shocks	Amain Hobbies	$ 30.00	$ 22.49	2	$ 44.98
ABS3D001	ABS3D001	Front Caster Block	3D Printed	$ 10.00	$ 6.00	0.716	$ 4.30
ABS3D002	ABS3D002	Upper Control Arm	3D Printed	$ 10.00	$ 6.00	1.64	$ 9.84
ABS3D003	ABS3D003	Rear Hub Carrier	3D Printed	$ 10.00	$ 6.00	0.526	$ 3.16
ABS3D004	ABS3D004	Steering Knuckles	3D Printed	$ 10.00	$ 6.00	0.378	$ 2.27
B000SU0J12	STR04	Steering Linkages	Amazon	$ 5.00	$ 7.90	1	$ 7.90
B01KJOCK4K	SUS02	Driveshaft	Amazon	$ 20.00	$ 19.99	1	$ 19.99
TLR332055	SUS03	Front Axle	Amain Hobbies	$ 10.00	$ 15.99	1	$ 15.99
STR05	STR05	Bell Crank	Salvaged	$ 10.00	$ -	1	$ -
8539K101	NYL001	Servo Mount	6" x 6"x 1/2" Nylon 6/6 (McMaster Carr)	$ 5.00	$ 11.88	1	$ 11.88
92949A160	FSTN01	Screws	1-1/4" #6-32 18-8 Stainless Steel Hex Drive Screw (McMaster Carr) (100 count)	$ 5.00	$ 6.51	1	$ 6.51
91841A007	FSTN02	Nuts	#6-32 18-8 Stainless Steel Hex Nut (McMaster Carr) (100 count)	$ 5.00	$ 3.40	1	$ 3.40
2636A23	-	Tap	#6-32 Long-Life Tap (McMaster Carr)		$ 6.06	1	$ 6.06
26865A51	-	End Mill	4 Flute, 1/8" End Mill for Aluminum (McMaster Carr)		$ 12.59	1	$ 12.59
Total				**$ 250.00**			**$ 246.39**

Table 2- Purchase List

Vendor ID	Part Name	Source	Cost
F438212	36-1/4" x 4" x 1/4" Aluminum 6061-T6 Flat Bar	Cut2Size	$ 30.32
S318T6	14" x 14" x 1/8" Aluminum 6061-T6 Sheet	Cut2Size	$ 24.74
B073F92G2S	Servo	Amazon	$ 17.99
YEA-DDL-090OR	Shocks	Amain Hobbies	$ 44.98
B000SU0J12	Turnbuckles	Amazon	$ 7.90
B01KJOCK4K	Rear Driveshaft	Amazon	$ 19.99
TLR332055	Front Axles	Amain Hobbies	$ 15.99
8539K101	6" x 6" x 1/2" Nylon 6/6	McMaster-Carr	$ 11.88
92949A160	1-1/4" #6-32 18-8 Stainless Steel Hex Drive Screws	McMaster-Carr	$ 6.51
91841A007	#6-32 18-8 Stainless Steel Hex Nuts	McMaster-Carr	$ 3.40
2636A23	#6-32 Long Life Tap	McMaster-Carr	$ 6.06
26865A51	4 Flute, 1/8" End Mill for Aluminum	McMaster-Carr	$ 12.59
CWU001	CWU Rapid Prototyping 1/26/2018	CWU	$ 14.94
94453	Waterjet Cutting	Alcobra Metals	$ 203.50
CWU002	CWU Rapid Prototyping 2/8/2018	CWU	$ 18.14
85461-RCPLANET2	Suspension Pins and Bearing	RC Planet	$ 31.59
CWU003	CWU Rapid Prototyping 2/13/2018	CWU	$ 19.98
CWU004	CWU Rapid Prototyping 2/22/2018	CWU	$ 10.62
3344093	Rear Driveshaft Hex Nuts	Amain Hobbies	$ 11.89
Total			**$ 513.01**

Appendix D - Schedule

Figure 37 - Gantt Chart of the project

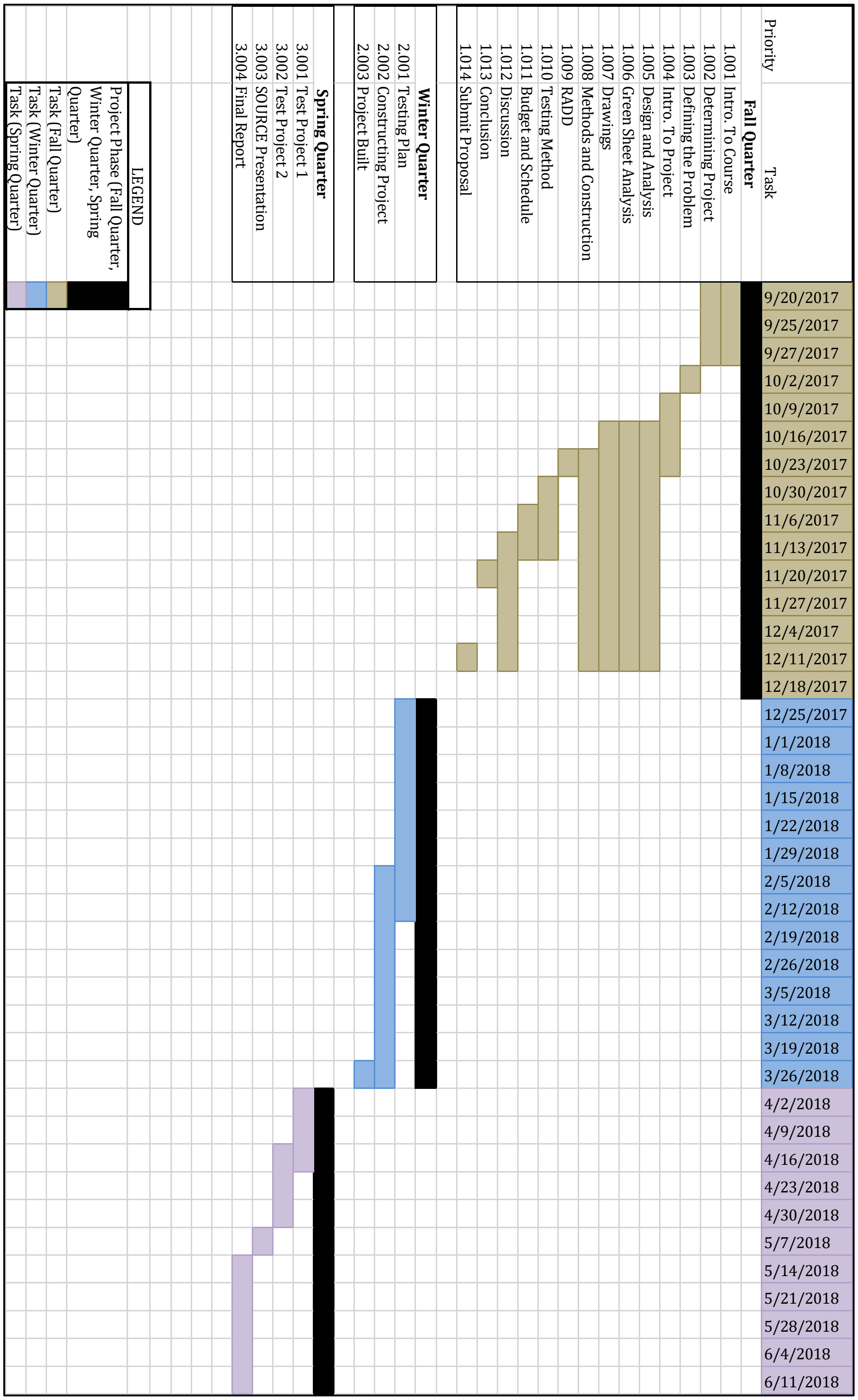


Figure 38 - Fall Quarter Gantt Chart Schedule

Focused Fall Quarter Schedule			Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Task ID	Tasks	Duration (hrs)												
F.001	Project Approval	1.00												
F.002	Create Website	4.00												
F.003	Function Statements	6.00												
F.004	Requirement Statements	6.00												
F.005	Design/RADD	10.00												
F.006	Analysis	10.00												
F.007	Methods & Construction	4.00												
F.008	Testing & Predictions	4.00												
F.009	Testing Methods	4.00												
F.010	Schedule	5.00												
F.011	Budget	3.00												
F.012	Drawings	8.00												
F.013	Presentation	2.00												
F.014	Finished Proposal (12/8/2017)	2.00												
Total Time		69.00												

Figure 39 - Schedule for the winter quarter manufacturing

ASME RC Baja Car: Suspension and Steering

Focused Winter Quarter Schedule

Task ID	Description	Estimated Duration (hrs)	Actual Duration (hrs)	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Winter Quarter Assignments and Orders		13.83	9.83												
A.000	Order Raw Material	0.50	0.50	31-Dec	4-Jan										
A.001	Fix Proposal and Report	2.00	2.00		7-Jan										
A.002	PSR and MfgProcess1	2.00	2.00		7-Jan										
A.003	Order Bought Parts	1.00	1.00				19-Jan	26-Jan							
A.004	Upload Website URL	0.08	0.08			10-Jan									
A.005	PSR3	1.00	0.50			12-Jan									
A.006	Mfg01	0.25	0.25			18-Jan									
A.007	PSR4	1.00	0.50				22-Jan								
A.008	PSR5	1.00	0.50					29-Jan							
A.009	PSR6	1.00	0.50						5-Feb						
A.010	PSR7	1.00	0.50							12-Feb					
A.011	PSR8	1.00	0.50								19-Feb				
A.012	PSR9	1.00	0.50									26-Feb			
A.013	PSR10	1.00	0.50										2-Mar		
Fabrication															
Chassis Plate		6.00	8.50												
1.000	Cut To Size	1.00	1.50				16-Jan								
1.001	Milling	2.00	2.00				16-Jan								
1.002	Drilling	3.00	5.00				16-Jan								
Shock Tower		4.00	5.00												
2.000	Send to Alcobra for Waterjet	1.00	1.00						2-Feb		15-Feb				
2.001	Drilling	2.00	2.00						2-Feb		15-Feb				
2.002	Tapping	1.00	2.00						2-Feb		15-Feb				
Suspension Mount		7.00	1.00												
3.000	Send to Alcobra for Waterjet	1.00	1.00						2-Feb	8-Feb					
3.001	Drilling	3.00	3.00						2-Feb	8-Feb					
3.002	Tapping	3.00	3.00						2-Feb	8-Feb					
Lower Control Arm		1.00	1.00												
4.000	Send to Alcobra for Waterjet	1.00	1.00						2-Feb						
Camber Link		6.50	6.25												
5.000	Prepare STL	0.50	0.25									22-Feb			
5.001	Printing	6.00	6.00									22-Feb			
Steering Knuckle		6.50	6.25												
6.000	Prepare STL	0.50	0.25				19-Jan	26-Jan							
6.001	Printing	6.00	6.00				19-Jan	26-Jan							
Caster Block		6.50	6.25												
7.000	Prepare STL	0.50	0.25					26-Jan							
7.001	Printing	6.00	6.00					26-Jan							
Upper Control Arm		12.50	6.25												
8.000	Prepare STL	0.50	0.25					26-Jan							
8.001	Printing	12.00	6.00					26-Jan							
Hub Carrier		6.50	6.25												
9.000	Prepare STL	0.50	0.25						31-Jan						
9.001	Printing	6.00	6.00						31-Jan						
Servo Mount		6.50	8.00												
10.000	Cut to Size	1.00	3.00							8-Feb					
10.001	Milling	2.00	3.00							8-Feb					
10.002	Drilling	2.00	1.00							8-Feb					
10.003	Tapping	1.50	1.00							8-Feb					
Construction		24.00	25.00												
11.000	Assemble Front Suspension	5.00	8.00								16-Feb				
11.001	Assemble Rear Suspension	5.00	6.00									23-Feb			
11.002	Assemble Steering System	10.00	6.00										2-Mar		
11.003	Complete Assembled Car	4.00	5.00										2-Mar		
Finishing Touches		48.00	47.00												
12.000	Fully Functional RC Car	5.00	5.00											8-Mar	
12.001	Updated and Complete Webpage	10.00	10.00											8-Mar	
12.002	Completed Report	30.00	31.00												14-Mar
12.003	Prepare Testing Methods and Equipment	3.00	1.00												16-Mar
Total Duration of Project		**148.8**	**136.58**												

Figure 40 - Gantt chart for spring quarter testing and presentation

ASME RC Baja Car: Suspension and Steering														
Focused Spring Quarter Schedule														
Task ID	Task Description	Estimated Time (hrs)	Actual Time (hrs)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Testing Methods		26.00	0											
13.001	Prepare Car for Drop Test	5.00		**27-Mar**	→	→	**19-Apr**							
13.002	Perform Drop Test	3.00					**19-Apr**							
13.003	Prepare Car for Slalom and Accel. Test	5.00				**9-Apr**	→	→	**4-May**					
13.004	Perform Slalom and Accel. Test	3.00							**4-May**					
13.005	Prepare Car for Terrain Test	7.00					**16-Apr**	→	→	**11-May**				
13.006	Perform Terrain Test	3.00								**11-May**				
Competition and Presentation		11.00												
14.001	Competition	5.00									**18-May**			
14.002	Prepare SOURCE Presentation	4.00		**27-Mar**	→	→	→	→	→	→	**15-May**			
14.003	Presentation	2.00										**16-May**		
Total Duration of Quarter		**37.00**												

Appendix E – Evaluation Sheet (Testing)

Evaluator: Hunter Jacobson	Date: April, 24th, 2018
Drop Test from 2 feet (1st Attempt)	Pass/Fail?: Fail
Comments: Car bottomed-out and multiple parts broke. Parts broken included both steering knuckles and one rear hub carrier.	
Drop Test from 2 feet (2nd Attempt)	Pass/Fail?: Fail
Comments: Car did not bottom-out, shocks fully closed, no broken parts. The first test was from 1 foot. The car displaced by an estimated 1.125 inches. Based on video footage, the car would not have likely survived a drop from a greater height, so the drop test was not resumed	
Climbing Test	Pass/Fail?: N/A
Comments: Due to time constraints, this test was not performed. The test would have included climbing over the long side of a 2” by 4” board.	
Straightness Test	Pass/Fail?: N/A
Comments: Due to time constraints, this test was not performed. The test would have included having the car’s maximum deviation over 30 feet no more than 6 inches.	

Appendix F – Testing Report

Introduction

The primary was to test the RC Baja car's steering and suspension will be to use the environment both within Hogue Hall and the outside environment. Inside of Hogue Hall, the environment can be controlled where obstacles and the ASME Baja challenges courses and be built and the RC Baja car can be run through a course that would be similar to what the final ASME Baja challenge courses would be, In the outside environment, there are multiple factors that are uncontrolled and the RC Baja car will be subject to uncertainty. The RC Baja car can be placed on dirt, rocks, or in a wet or dry environment where the RC Baja car can be tested to see if it can operate in different environments that it would not normally operate.

Requirements

1. Survive a 2-foot drop onto concrete and drive away, operating as expected.
2. Drive within a 12 inch wide, 30-foot long section without moving outside of the marked zone
3. Climb over a system of 2x4 boards with the long side parallel to the ground.

Approach

The tests will primarily take place inside of Hogue Hall where the environment can be created and controlled. This environment is ideal as there are multiple resources available so that many challenges, tests, and courses that can be created in a controlled environment. Some of these resources include boxes, lumber, concrete, and raised platforms can be used to control the height of the RC Baja car if a drop test was performed. If a simulation of the outside environment was to be performed, there are multiple types of surfaces and conditions that can be brought in from the outside and recreated inside of Hogue Hall.

Procedure

When testing the ability of the suspension of the RC Baja car to absorb a 2-foot drop test, the RC Baja car will drive off of a raised, measured surface. For this test to be measurable, the height of the raised surface along with the final mass of the RC Baja car will be needed to calculate the energy the car is expected to absorb. This test will be graded on a pass/fail system. To pass this test, the RC Baja will need to operate as expected after driving and fall off the raised surface.

When testing the ability of the RC Baja car to drive in a straight manner, the RC Baja car will be put through a course where two 30 foot lengths of tape will be placed on the ground parallel to each other at a width of 12 inches. The RC Baja car will be making multiple runs between the two lengths of tape at varying speeds. This test will be graded on a pass/fail system. To pass this test, the RC Baja car must not have one wheel fully outside of either length of tape during the run of the course. This test will be running at 10%, 25%, 50%, and 100% of the maximum speed possible.

When testing the ability of the RC Baja car to climb onto and over obstacles, a system of 2x4 boards will be fastened to the ground. The boards will either increase or decrease in height at an interval of 1.5 inches. The RC Baja car can move through this course at any speed as long as the RC Baja car continues to move forward. To pass this test, the RC Baja car will need to complete the course fully without failing to cross over any of the boards or tipping or falling over.

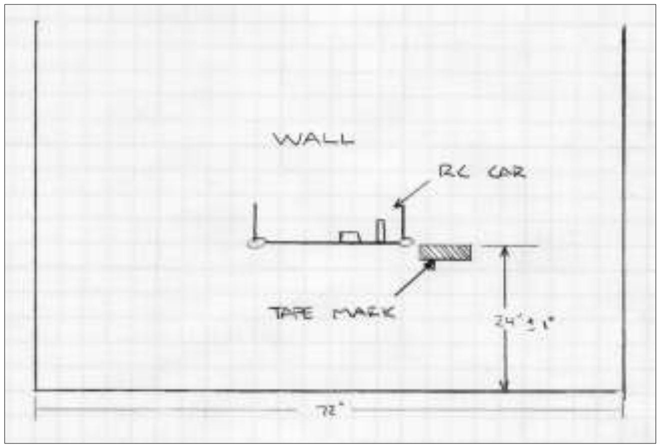
The following test procedure represents that step-by-step process that will be followed for the drop test:

To complete the drop test of the RC car, the following actions will need to take place in order to be successful:

1. Find an area that extends from a wall in the Material's Lab and is clear from any obstruction in a 6-foot by 6-foot area. The wall may not have any obstructions, such as tables or windows.
2. Have one person use the tape measure or ruler to measure out 24 inches from the ground up the wall. This measurement may be made with a tolerance of ±1 inch.
3. Have another person mark the measurement on the wall using tape, where the bottom of the tape will represent the 24-inch measurement. It is suggested that a tape that is colored is used, such as Scotch-Blue, or colored duct tape.
4. One person will set up with the camera so that the entire RC car, the tape measurement, and the ground can all be seen through the viewfinder. If a cell phone camera, keeping the camera and phone steady during the operation is crucial in making sure that the video accurately captures the test. If using a DSLR, it is suggested that a tripod is used to ensure that the video is steady.
5. Another person will be holding the RC car in both hands, by placing the bottom of the chassis plate onto the top of the hands. The person operating the camera will help the person holding the car to align the bottom of the wheel with the bottom mark of the tape measurement. Since accuracy may be difficult to obtain with this test, having the RC car as close as possible to the bottom of the tape will be sufficient. The person holding the car will have the car about 3 feet away from the wall to ensure that the RC car does not contact the wall during the test.
6. Once both people have communicated that the test is ready, the person behind the camera will begin recording the video and will count down from 3. Once the person behind the camera reached zero, the car will be dropped from the person holding the car by quickly moving their hands to the outside, away from the RC car.
7. Once the RC car contacts the ground and is resting, the person behind the camera will stop the video.
8. The person that was behind the camera, will take control of the RC car remote, and attempt to drive the RC car, testing the forward motion, reverse, and steering systems.
9. If the RC car operates normally during the driving of the RC car, the team will turn off the RC car and begin visually inspecting the RC car, looking for any failures of the

mechanical parts of the RC car. If no visual failures are seen on the RC car, the test will be considered successful. If any parts have wholly failed, such as complete breakages, bent parts, or seized parts, the test will be considered a failure.

10. If the RC car does not operate normally during the driving of the RC car, the test will be considered a failure.



The primary risk involved with performing this test is the condition of the RC car. If the RC car sustains heavy damage as a result of this test, extensive repair may be necessary to have the RC car in a working state. The repair would expectedly take significant time to perform and at a great cost. The analysis that was done in preparation for the testing shows that the RC car will survive this test, with the understanding that the RC car lands wheels-first. If for some reason, when the test was performed and the RC car was flipped, it may likely produce a failure in the shock towers first, as this is the most prominent feature coming out of the top of the RC car. This scenario may happen during competition, but would unlikely occur from a height of 2 feet. Although the flipping of the RC car during competition is likely to occur, it is not expected that the RC car will experience failures.

The safety of the test performers and those nearby observing the test will be watched carefully. Although there are no significant hazards posed to those nearby by RC car, the only issue that could arise may be parts that bounce quickly away if extreme failure were to occur, such as springs bouncing away and hitting somebody.

Results

Due to time constraints and the results of the testing, only the drop test could be performed with the RC car. During the first drop test of the RC car, the suspension did not adequately absorb the impact when the RC car was dropped from 2 feet. This caused the RC car to "bottom-out" and multiple part failures occurred as a result. To address the failed test, the shocks that were purchased for the RC car came with multiple sets of springs that could be changed to allow for different stiffness's. Although the shocks did not come with any stated spring rate, the team decided on a set of springs that did not allow the RC car to noticeably move the shocks when at rest. With these second set of springs installed, the team performed a second drop test, starting at 1 foot, and incrementing up at ½ feet with each test. When the team started the second drop test, video footage that was available showed that the springs had fully collapsed, and did not fully absorb the impact. While the RC car did not "bottom-out" during the second test, the team did not have enough confidence that the RC car may survive the 1.5 foot and 2-foot drop tests and decided to not continue with the test.

Test	Pass or Fail
1st Drop Test	Fail
2nd Drop Test	Fail
Straightness Test	N/A
Climbing Test	N/A

Moving forward, to allow the RC car to pass the drop test in the future, it will be necessary to reduce the weight of the RC car so that the spring will fully absorb the impact of the drop. The RC car is made nearly completely out of aluminum provided a much heavier car than expected and based on the condition that was present at the competition, the strength properties of aluminum would most likely not be required for the RC car. Using alternative materials, such as plastics, would have provided adequate strength for the RC car while reducing the weight of the RC car significantly.

Appendix G – Testing Data

Evaluator: Hunter Jacobson	Date: April, 24th, 2018
Drop Test from 2 feet (1st Attempt)	Pass/Fail?: Fail
Comments: Car bottomed-out and multiple parts broke. Parts broken included both steering knuckles and one rear hub carrier.	
Drop Test from 2 feet (2nd Attempt)	Pass/Fail?: Fail
Comments: Car did not bottom-out, shocks fully closed, no broken parts. The first test was from 1 foot. The car displaced by an estimated 1.125 inches. Based on video footage, the car would not have likely survived a drop from a greater height, so the drop test was not resumed	
Climbing Test	Pass/Fail?: N/A
Comments: Due to time constraints, this test was not performed. The test would have included climbing over the long side of a 2” by 4” board.	
Straightness Test	Pass/Fail?: N/A
Comments: Due to time constraints, this test was not performed. The test would have included having the car’s maximum deviation over 30 feet no more than 6 inches.	

Appendix H - Media

Figure 41 - Photo of the chassis plate being milled to size

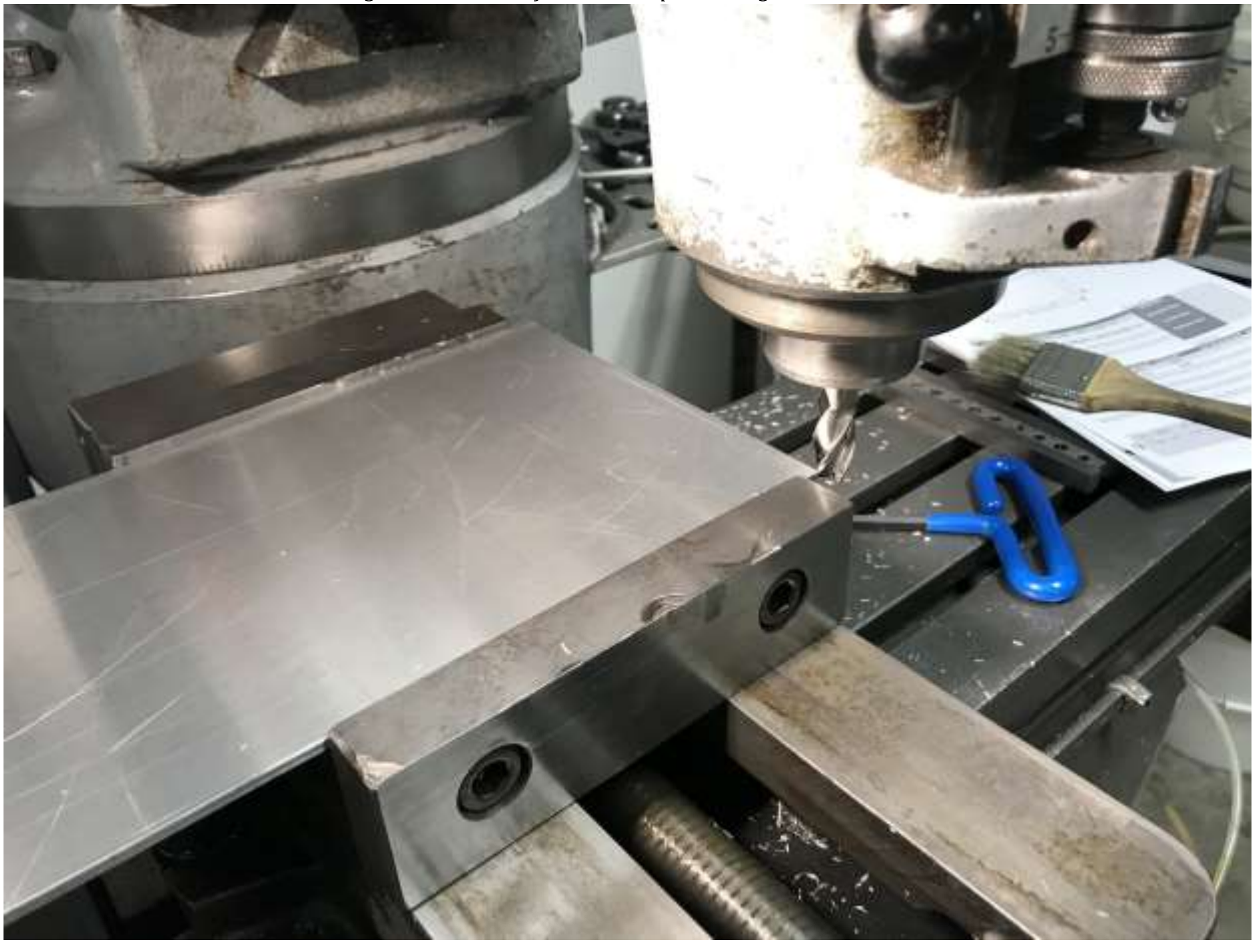


Figure 42 - Photo of the chassis plate having holes drilled through

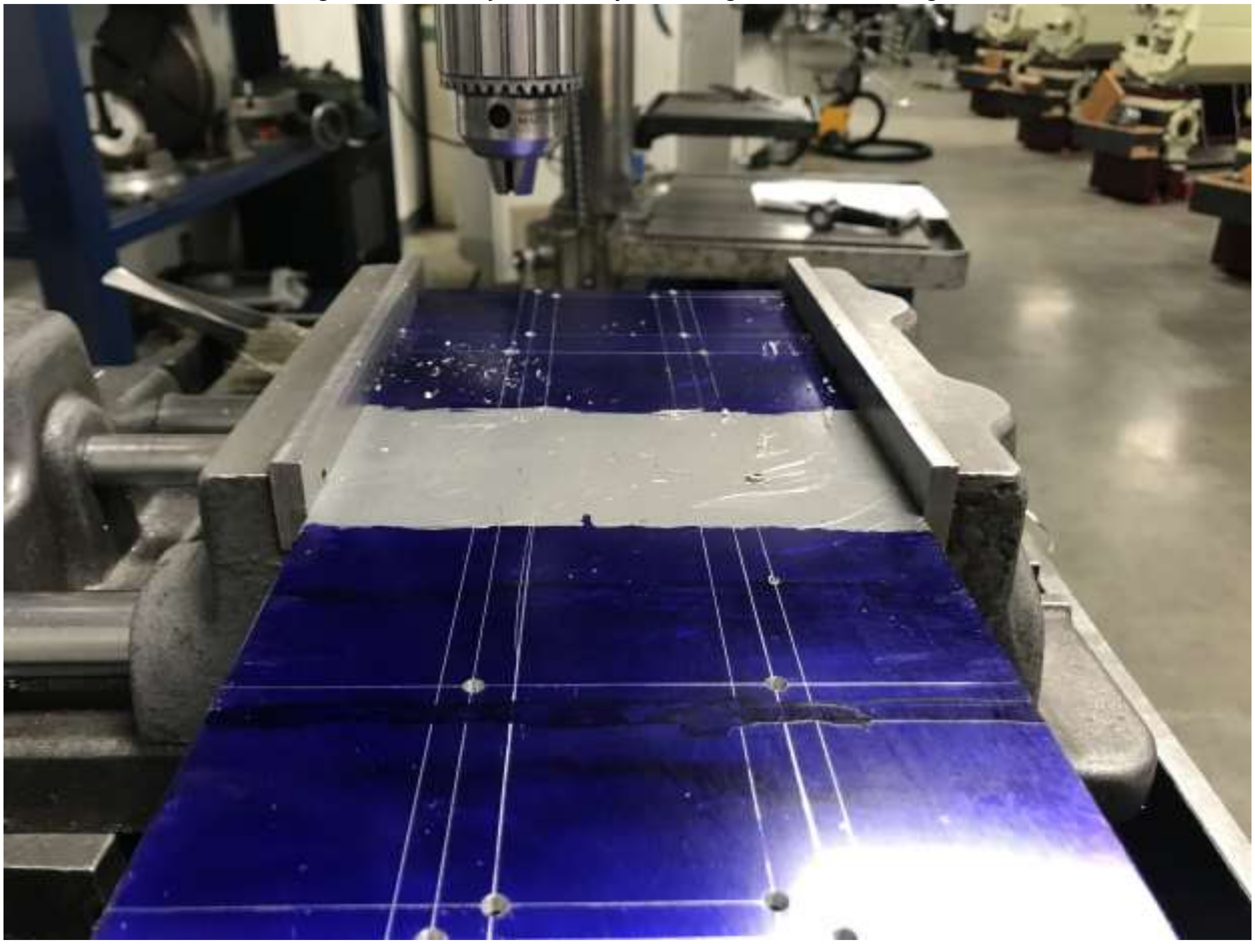


Figure 43 - Photo of the suspension mount being drilled to size

Figure 44 - Photo of the servo mounts being milled to size

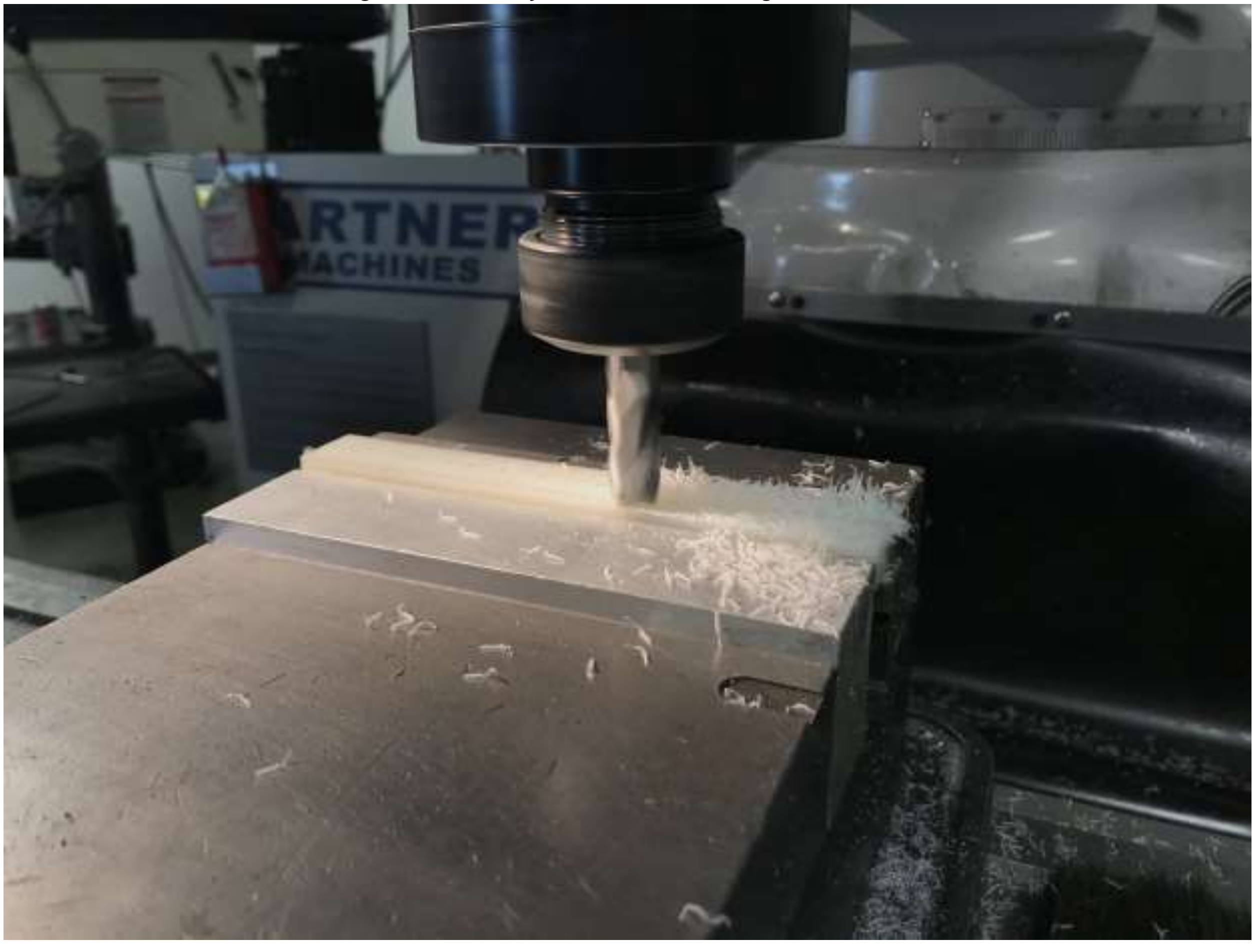


Figure 45 - Photo of the suspension mount holes being tapped

Figure 46 - Photo of the parts to the RC Baja car in their completed state

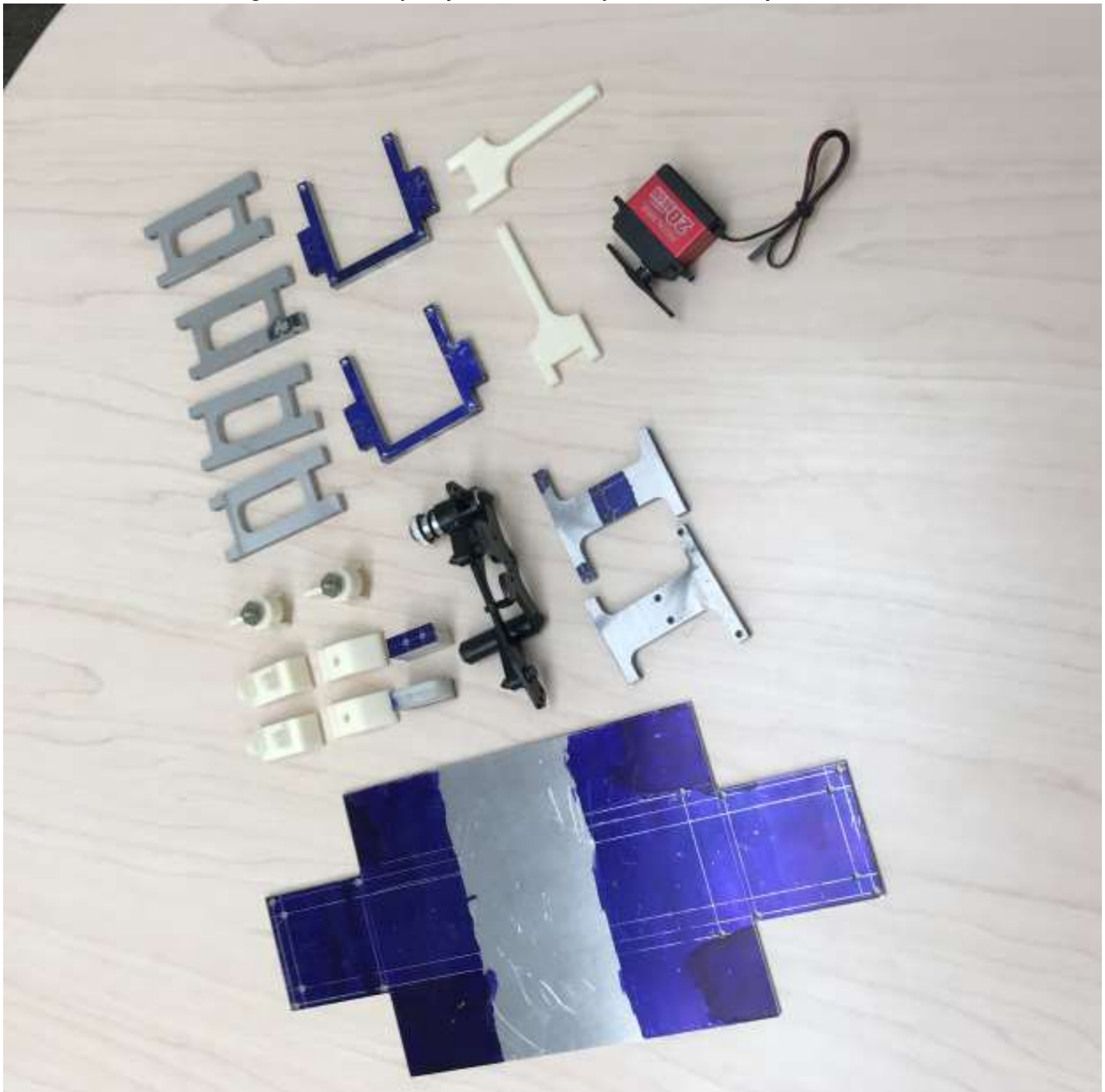


Figure 47 - Photo of the finished assembly of the RC Baja car

Appendix I – Resume

Figure 48 - Resume

HUNTER W. JACOBSON

2925 THORNHILL RD I PUYALLUP, WA 98374
(253) 389-3774 I HUNTER.JACOBSON@OUTLOOK.COM

RELEVANT SKILLS

- Proficient and certified in SolidWorks
- Soon-to-be college graduate
- Fenestration industry experience
- 2D and 3D design
- Knowledgeable in quality systems
- Programmable logic controller understanding
- Internship experience

EDUCATION

Central Washington University, Ellensburg, WA
Bachelor of Science, Mechanical Engineering Technology, Class of 2018

- Relevant Coursework: Finite Element Analysis, AutoCAD, Programmable Logic Controllers, Quality Control
- Capstone Project: ASME RC Baja Challenge with the design, manufacture, and construction of the suspension and steering system

EXPERIENCE

Central Washington University, Ellensburg, WA - Resident Assistant
September 2017 - Present

- Voted Student Staff Member of the Year by immediate colleagues living within the same residence hall
- Acted as a resource for new and returning students residing within the residence halls
- Facilitated and advised programs and events for residents to develop the residence hall community
- Advised the residence hall leadership council in financial, programming, and leadership methods to allow leaders within the residence hall to grow as future school leaders
- Helped with the coordination of student staff selection for the 2018 - 2019 school year; working with approximately 35 other current student staff members

Milgard Windows & Doors, Fife, WA - Design Engineer Intern
June 2017 - September 2017

- Modified window handles and weather-stripping on multiple product lines to same the company upwards of $125,000 per year
- Analyzed different trim options on multiple styles of windows to determine if the removal would have a significant impact on cost savings and performance
- Worked within a team of 10 engineers, managers, and technicians to explore possible areas of cost savings throughout each product line
- Explored areas of potential waste and utilized company Kaizen events to explore potential areas of cost savings and safety concerns throughout multiple production warehouses

Domino's Pizza, Puyallup, WA - Delivery Driver
March 2014 - September 2016

- Showcased attention to detail while balancing timeliness during the making of pizzas, sides, and desserts so that customers received a high quality meal within a reasonable time frame
- Implemented the city block numbering system into deliveries to reduce to use of GPS, decreasing the time customers waited for their order after it left the store

RELEVANT PROJECTS

ASME RC Baja Challenge: Suspension and Steering - Central Washington University - Ellensburg, WA

- Designed the suspension and steering components of an electrically-driven RC Baja Car using 3D software such as SolidWorks and Onshape.
- Manufactured components of the RC Baja Car using traditional machining, waterjet cutting, and additive manufacturing.
- Constructed the RC Baja Car on-site to compete in a competition featuring four other teams.

Modifying the SmartTouch Lock Handle - Milgard Window & Doors - Fife, WA

- Modified the SmartTouch Lock Handle to reduce material usage in an effort to promote cost savings without impacting performance. Material usage was reduced by 7% and removed one manufacturing process without changing the operation of the handle for a potential cost savings of $75,000 per year.